Studies on the Impact of Municipal Sewage Discharged onto an Intertidal Area Within the Fraser River Estuary, British Columbia

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STUDIES ON THE IMPACT OF MUNICIPAL SEWAGE DISCHARGED ONTO AN INTERTIDAL AREA WITHIN THE FRASER RIVER ESTUARY, BRITISH COLUMBIA

by

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PREFACE

The discharge of municipal sewage and other wastewaters into the estuary of the Fraser River has been the topic of considerable discussion within formal public hearings and meetings over the last few years. Concern has been expressed over the adequacy of waste treatment and other controls necessary to protect and maintain aquatic resources in the industrialized and urban areas which constitute the lower mainland of British Columbia. This concern has been particularly focused on the lower Fraser River and its estuary, resulting in the assembly of pertinent information by the Federal and Provincial governments in an attempt to determine the current environmental status of, and develop plans for, river and estuary management.

The research results presented in this document validate some of the concerns that have been raised over the discharge of wastes into the Fraser River estuary. As a result of these findings Federal and Provincial representatives in association with the Greater Vancouver Sewerage and Drainage District are currently assessing methods whereby the environmental impact of the municipal waste from the Iona Island sewage treatment plant can be minimized.

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ABSTRACT

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A major sewage treatment plant at Iona Island discharges up to 1.53 x 10^6 m^3 d^{-1} of combined stormwater, domestic and industrial waste onto the intertidal area of Sturgeon Bank in the estuary of the Fraser River. At low tide the effluent is conveyed across extensive sandflats within a dredged channel which extends more than 6 km into Georgia Strait. The preliminary studies presented here were carried out to assess the effects of the effluent on water quality, fish survival, distribution and abundance.

A total of 7470 fish (comprising 20 species) was captured from 11 sampling sites between May 26 and July 2, 1980. Juvenile Pacific herring were numerically dominant in the catch (39%), but juvenile chinook salmon occurred most frequently (20.5%). The intertidal zone near the sewage outfall was underutilized by fish; no salmonids were captured at sites closer than 1 km to the outfall. Signficantly more fish (6717) were captured at 4 sampling sites in an unpolluted adjacant area compared with the catches (753) from 7 sites within the area receiving sewage effluent.

The survival of juvenile chinook salmon during in-situ bioassay experiments increased with distance from the sewage outfall, however, fish mortality occurred at all experimental sites within 4.4 km from the outfall. Mortality often was rapid and on one occasion all the test fish placed 2.2 km from the outfall died within 9 minutes. The low levels of dissolved oxygen which resulted from the discharge of sewage were probably a contributing factor in the mortality of the caged fish.

During calm, and warm weather, receiving waters overlying part of Sturgeon Bank became depleted of dissolved oxygen. This event was often associated with fish stress, mortality, and extensive predation by gulls and herons. It is suggested that this frequent mortality of large numbers of fish could have a deleterious effect on fish stocks in the Fraser estuary.

An examination of organic contaminants in fish tissue revealed the presence in flounders and a sculpin of aromatic aldehydes and acids present in municipal wastewaters. These fish also contained a dichloroanisole of uncertain origin and persistence. A number of chlorinated hydrocarbon pesticides, PCB's and chloro- and nitrophenols were detected at trace levels in a sample of flounders taken in 1978. Several volatile organic compounds, chiefly solvents, were measured in seawater samples in the area of the outfall. These substances were present at concentrations well below their incipient lethal levels.

Key words: Fraser River estuary, municipal wastes, juvenile salmon, contaminants, habitat.

RESUME

Birtwell, I. K., G. L. Greer, M. D. Nassichuk and I. H. Rogers. 1983. Studies on the impact of municipal sewage discharged onto an intertidal area within the Fraser River estuary, British Columbia. Can. Tech. Rep. Fish Aquat. Sci. 1170: ix + 55 p.

Une importante usine d'épuration des eaux d'égout, située sur l'île Iona, décharge jusqu'à 1,53 x 10^6 m^3 d^{-1} d'eau pluviale, d'eaux usées domestiques et d'eaux résiduaires industrielles dans la zone intertidale du banc Sturgeon dans l'estuaire du fleuve Fraser. À marée basse, l'effluent est transporté dans de grands veys le long d'un chenal draqué qui s'avance sur plus de 6 km dans le détroit de Géorgie. On présente les études préliminaires menées afin d'évaluer l'incidence de l'effluent sur la qualité de l'eau et la survie, la répartition et l'abondance des poissons.

Au total, 7 470 poissons appartenant à 20 espéces ont été capturés à 11 sites d'échantillonnage du 26 mai au 2 juillet 1980. Les harengs du Pacifique juvéniles constituaient, en nombre, la plus grande partie de la prise (39%), mais les saumons quinnats juvéniles étaient pris le plus souvent (20,5%). La zone intertidale prés de la décharge d'eaux usées était peu fréquentée par les poissons. Aucun salmonidé n'a été pris aux sites à moins d'un km du dégorgeoir. Un nombre beaucoup plus grand de poissons (6 717) ont été pêchés aux 4 emplacements dans la région adjacente non polluée en comparaison des prises (735) à 7 endroits à l'intérieur de la zone qui reçoit les eaux usées.

Au cours de tests biologinques in-situ, la survie de saumons quinnats juvéniles a augmenté en fonction de la distance de la décharge des eaux usées. Toutefois, des possons sont morts à tous les sites expérimentaux jusqu'à 4,4 km du dégorgeoir. La mort était souvent rapide et à une occasion, tous les poissons testés placés à 2,2 km de la décharge sont morts en moins de 9 minutes. Les faibles niveaux d'oxygène dissous causés par la décharge d'eaux usées constituent probablement un des facteurs ayant provoqué la mort des poissons en cage.

Par temps calme et chaud, lex eaux d'une partie du banc Sturgeon où se déverse l'effluent devenaient très pauvres en oxygène dissous. Chez les poissons, ce fait était souvent associé au stress, à la mortalité et à une importante prédation par les goélands et les hérons. Nous formulons l'hypothèse que cette mortalité fréquente d'un grand nombre de poissons peut se traduire par un effet nuisible pour les stocks de l'estuaire du Fraser.

Une étude des éléments organiques polluants dans les tissue des poissons a révélé la présence, chez les flets et un chabot, d'aldéhydes et d'acides aromatiques se trouvant dans les eaux usées municipales. Ces espèces contenaient aussi un dichloroanisole dont l'origine et la rémanence sont inconnues. Un certain nombre d'hydrocarbures chlorés (pesticides), de BPC et de chloro- et nitrophénols à l'état de trace ont été découverts dans un échantillon de flets capturés en 1978. Plusieurs composés organiques volatiles, surtout des solvants, ont été quantifiés dans des échantillons d'eau de mer dans la région de la décharge. La concentration de ces substances était très inférieure à leur niveau létal d'origine.

Mots-clés: estuaire du fleuve Fraser, eaux usées municipales, saumon juvénile, éléments polluants, habitat

INTRODUCTION

The Greater Vancouver Sewerage and Drainage District (G.V.S.&D.D.) has,since 1964, operated a major sewage treatment plant on Iona Island in the Fraser River estuary, British Columbia. The flow of effluent from this plant constitutes the largest single municipal discharge in British Columbia and its impact on the estuarine receiving area has been the topic of a number of investigations. Attention has focused on the impact on benthic organisms, sediment and water chemistry, and bacteriology (B.C. Research 1973, 1975, 1977; Otte and Levings 1975; Dunn and Stich 1976; McGreer 1979; Levings et al. unpublished MS), the contamination of organisms by heavy metals and organic compounds (Parsons et al. 1973; B.C. Research 1974, 1977; Beak Consultants Ltd. 1980; Brown et al. 1977; Dept. of Fisheries and Oceans; Dept. of Environment - unpublished data; E.V.S. Consultants Ltd. 1979; Radian Corporation 1979; Vermeer and Peakall 1979), the physical environment in the vicinity of the discharge (Tabata et al. 1971), the chemical and physical characteristics of the effluent (Cain et al. 1980), and its toxicity to fish (G.V.S.&D.D. - unpublished data; Tanner et al. 1973; Martens and Servizi 1976).

However, despite the findings of these studies which have, in general, indicated that the discharge of this effluent has resulted in environmental degradation, little attention had been directed towards assessing the effects on fishery resources in the Fraser River estuary.

This report details preliminary research on the effects of the sewage effluent on fish distribution and abundance in the intertidal zone receiving the wastes, fish survival using in-situ bioassays, aspects of water quality, and organic contaminant analyses.

The main aspect of this project, which was carried out in the spring and summer of 1980 and 1981, was a joint venture with the Field Services Branch (Water Quality Unit, Habitat Management Division) and the Fisheries Research Branch (Pollution and Toxicology Group, Salmon Habitat Section) of the Department of Fisheries and Oceans. A summary of earlier work on chemical analyses of effluent, receiving waters, and fish tissues from 1978 to 1980 is also included in the present report. The study relied on the full cooperation of the G.V.S.& D.D.

STUDY LOCATION

Iona Island is in the estuary of the Fraser River. It lies north of the Vancouver International Airport on Sea Island and is bounded by the north arm of the Fraser River, McDonald Slough and Sturgeon Bank in Georgia Strait (Fig. 1).

Rawn et al. (1953) recommended Iona Island as the location of a major sewage treatment plant to provide treatment for domestic and industrial wastes and stormwater. The sewage is collected from an area of about 14,400 ha serving

a population of about 500,000. Effluent flow rates of less than 942,000 $m^3\ d^{-1}$ were given primary treatment but flows exceeding this level (to a maximum of about $1.53 \times 10^6\ m^3\ d^{-1}$) received little or no treatment.

Effluent from the treatment plant is discharged westwards onto the high intertidal zone of Sturgeon Bank. At low tide the effluent flows along a dredged channel which extends almost 7 km across the sandflats. A rock jetty parallels the effluent channel on its north side for about 4 km and effectively restricts the dispersion of effluent to the southern portion of Sturgeon Bank. For public health concerns, the effluent is chlorinated prior to discharge between May and October.

BIOLOGICAL RESOURCES

The importance of the estuarine area presently receiving effluent from the Iona Island sewage treatment plant is, in part, exemplified by the economic value associated with Pacific salmon which migrate through and rear in the estuary (Table 1) together with information on the commercial value of non-salmonids caught in the vicinity of the Fraser River and adjacent areas of Georgia Strait (Table 2). Furthermore, a significant part of the commerical fishery for crabs (Cancer magister) occurs close to the end of the dredged effluent channel as well as a shrimp fishery in adjacent deeper waters.

Information describing the use by juvenile salmon of the intertidal area of the "inner estuary" of the Fraser River has increased in recent years, (e.g. Levy and Northcote 1982) but less attention has been focussed on the "outer estuary" which lies seaward of the main land mass at high tide. Greer et al. (1980) documented the presence of 38 species of fish in these outer estuarine areas and it is apparent from more recent studies (C.D. Levings, pers. comm.) that a wide variety of fish species utilize these intertidal banks for extended periods of time.

When consideration is given to the importance of the biological resources of the Fraser estuary and the need to dispose of municipal wastes, a potential conflict clearly arises. Effluents which are usually less dense and warmer than the stratified waters they are discharged into tend to be dispersed within the upper part of the water column. Juvenile salmon also occupy the uppermost part of the water column during their migrating and rearing phase in estuaries, hence, there is the potential for direct conflict due to the need to dispose effluents into the upper part of the water column and the requirements of juvenile salmon and other fish which use the same strata of these receiving waters. The present studies were carried out to investigate this potential conflict.

METHODS

FISH SAMPLING

Collections of fish were made weekly on 6 occasions between May 26 and July 2 1980, at 11 sites (Fig. 2). The timing of sampling was specifically chosen to coincide with the downstream migration and estuarine rearing phase of juvenile salmon. Four of the sampling sites were along the north side of the rock jetty in the relatively effluent-free zone (B.C. Research 1973) and 7 sites were situated along the south side of the jetty - the usual dispersal path of the effluent (B.C. Research 1973). Fish were captured by deploying a 15 x 2.5 m beach seine from a small boat. Duplicate sets were made at each site and the sampling period was over approximately 4 h; 2 h either side of high tides between 3.8 and 3.9 m. Identification and enumeration of the catch occurred in the field, but a sub-sample of each species was taken and placed in buffered formalin for verification in the laboratory and determination of lengths and weights.

IN-SITU BIOASSAY EXPERIMENTS

Between June 17 and July 9, 1980, we examined the survival of juvenile chinook salmon (length 73.6 ± 1.9 mm, weight 7.40 ± 2.24 g) which had been held in water of 12.5‰ salinity and a temperature of about 9.9°C at the West Vancouver Laboratory. Juvenile chinook salmon were chosen because they have an extensive rearing period in the Fraser estuary (Levy and Northcote 1982). Prior to experimentation the fish were held for about 24 h at a site on the north side of the jetty, about 4.4 km from shore. Nine test sites were used and their location along the sewage effluent channel is shown in Figure 2. Woven nylon net cages of approximately 50-L capacity held 10 fish at 0.5 m depth at each site. The cages were held in position by anchored buoys. The survival of fish was checked at least daily, and frequently within minutes from the start of experimentation. Cessation of gill movement was the criterion used to indicate their death.

WATER CHEMISTRY VARIABLES

The dissolved oxygen content, temperature, conductivity, pH and oxidation-reduction potential were determined at each fish sampling and bioassay site on every sampling occasion. These recordings were made at 0.5 m depth at the fish capture sites but at the surface and at 0.5 m intervals at the bioassay sites. A multiprobe sensing unit (Hydrolab Corporation, Texas) was used to measure these variables in the water column; water samples were also collected by conventional means for dissolved oxygen determination by the Winkler technique.

Temporal and spatial determinations of the water chemistry variables over the usual effluent dispersal path employed a sampling grid of 12 sites, 3 sites south and across the effluent channel from each of 4 sites along the channel (see Fig. 7); each was marked by an anchored buoy. The area extended from approximately 1 km to 3.6 km seaward of the sewage outfall and approximately 300 m across the intertidal zone south of the Iona jetty. Additional sampling sites along the sewage channel were also examined.

ORGANIC CONTAMINANT ANALYSES

Analyses conducted by Radian Corporation

Fish muscle tissues

Tissue samples were from starry flounder (ca. 15 cm length) collected from two sites in the Iona sewage channel (ca. 1 km [SB-1] and 3 km [SB-2] from the outfall and a control site on Roberts Bank (RB-1) approximately 15 km south of the sewage channel. Fish collections were made mid-August and mid-November, 1978. Ten flounder from each of the three sites were shipped frozen to Radian Corporation, Texas, for analysis. The preparation of tissue extracts and analyses for contaminants by Radian Corporation (1979) were on 50 g portions of muscle tissue from composite samples of the specimens from each site. Heads and internal organs were discarded. The muscle tissue was mixed with sodium sulphate and extracted with solvent (hexane/methylene chloride, 85:15) in a Waring blender using 150 + 100 + 100 mL portions of the solvent. Each extract was filtered on a Buchner funnel and the filter cake washed with 100 mL solvent. The combined extracts were washed three times in a separatory funnel with 50 mL portions of 5% aqueous ammonium hydroxide solution to remove acidic components. The solution was then dried over sodium sulphate and concentrated to approximately 10 mL. The extract was chromatographed on a column of Florisil and the fraction, eluted with 250 mL petroleum ether/ethyl ether (94:6), was retained for base/neutral and PCB analyses. The aqueous ammonia extracts were combined, acidified and extracted three times with 50 mL portions of methylene chloride/ethyl ether (85:15). The combined extracts were concentrated to 0.5 mL in a Kuderna-Danish apparatus and methylated with diazomethane in preparation for analysis.

In further work by Radian Corporation (1980), base/neutral fractions of the SB-1, SB-2 and RB-1 flounder extracts were analyzed specifically for PCB's by gas chromatography using a Hall detector. The PCB analyses also included a tissue extract composited from a sample of juvenile chinook salmon captured at SB-1, in the August 1978 sampling. Preparation of the base/neutral fraction was as above for the flounder tissue. A solution of Arochlor 1254 was used as an external standard. Peaks with retention times identical with those in the standard were integrated to compute the PCB concentrations in the base/neutral extracts. Analysis for PCB's in the sewage samples was not carried out.

Unchlorinated Iona sewage

Three unchlorinated sewage grab samples collected from the Iona plant in November 1979 were shipped frozen to Radian Corp., Texas. The samples were mixed and a 1.5 L composite was made basic (pH 10.0), spiked with 75 µg each of d_8-naphthalene and pentafluorophenol and continuously extracted for 24 hours in a liquid/liquid extractor using methylene chloride solvent (600 mL). The solvent was removed, the pH adjusted to 2.0 and the extraction with methylene chloride repeated. Each extract was passed through a column of sodium sulphate to remove residual water and then concentrated to 10 mL in a Kuderna-Danish concentractor. A solvent blank was prepared from 600 mL methylene chloride.

Sample clean-up by gel permeation chromatography

A 2.5 x 45 cm column was charged with 40 g of Bio-Beads SX-3 conditioned with a 1:1 mixture of cyclohexane/methylene chloride. The concentrated base/neutral and acid extracts from each sewage sample were combined, added to the GPC column and eluted with 300 mL of 1:1 cyclohexane/methylene chloride at a rate of 6 mL min^{-1}. The fish extracts were treated similarly. For both the sewage and fish extracts, the first 100 mL eluate contained lipids and fatty acids and was discarded (see Tindle and Stalling 1972). The compounds of interest were recovered in a further 200 mL of eluate.

Each 200 mL eluate from the GPC column was passed through a 5 x 1 cm column of cesium hydroxide-treated silica gel into a Kuderna-Danish concentrator and concentrated to 1 mL, representing the base/neutral fraction. The acidic components, retained on the silica gel, were eluted into a Kuderna-Danish apparatus using 10 mL of a solution of methanol in acetone (1:4). This eluate also was concentrated to 1 mL.

Analysis by gas chromatography (GC) and mass spectrometry (GC-MS)

All samples were analyzed by GC on a Tracor dual column instrument equipped with a capillary column and flame ionization detector (FID). The column used for the acidic fractions was a 25 m x 0.2 mm I.D. fused silica capillary column wall coated with OV-101. For the base/neutral fractions the column was a 50 m x 0.5 mm I.D. glass capillary wall coated with SE-54. All samples were also analyzed on a Tracor 560 GC containing packed columns and a Hall 700 A electrolytic conductivity detector (HECD) in the halogen-specific mode. The acidic fractions were analyzed using a 1.82 m x 2 mm glass column packed with 1% SP-1240 DA on 100/120 mesh Supelcoport with helium as carrier gas. Base/neutral fractions were analyzed on a 1.82 m x 2 mm glass column packed with 3% SP-2250 DB on 100/120 mesh Supelcoport with helium as carrier gas.

Mass spectrometric data were recorded by analyzing the above extracts on a Hewlett-Packard 5985A GC-MS instrument. Spectra were obtained in electron impact mode at 70 electron volts. Extracts were spiked with d_{10}-anthracene prior to analysis and this compound was used to measure relative retention times. Base/neutrals were analyzed on the same column used in the GC-FID tests. Acidic fractions were analyzed on the packed column used in the GC-HECD tests. In both cases helium was the carrier gas.

Analyses conducted at the West Vancouver Laboratory

Fish muscle tissue

Fish tissue samples (50 - 100 g muscle, or whole animal) were from species (starry flounder, n = 13; staghorn sculpin, n = 1; shiner perch, n = 1); collected 14 August 1981 about 2 km seaward of the sewage outfall and at the confluence of the sewage channel and the natural drainage channel (Fig. 2). Tissues, or tissue composites in the case of flounder, were homogenized in water using a Brinkmann Polytron. The homogenates were acetylated in the presence of an excess of acetic anhydride and potassium carbonate. After two hours at room temperature the mixture was extracted three times with pesticide-grade hexane in a separatory funnel and the extract evaporated to 1 ml under a stream of nitrogen. After analysis of the extract for acetylated derivatives the extract was methylated with an ether solution of diazomethane, similarly concentrated and analyzed for methylated derivatives. Both extracts were analyzed under electron impact using a desk-top Hewlett Packard 5992 GC-MS instrument operating at 80 electron volts. Splitless injections were made onto an SE 54 capillary column (0.2 mm I.D.) temperature programmed from 30°C to 270°C at 10°C min^{-1} after an initial delay of 4 minutes to vent the solvent. Mass spectra were identified manually by reference to the Aldermaston Eight-Peak Index and to the Environmental Protection Agency - National Institute of Health (U.S.A.) Mass Spectral Data Base.

Sewage effluent receiving waters

Samples of surface water were collected in glass containers on July 29, 1981 at 7 sites approximately equidistant along the middle of the sewage channel at distances ranging from 0 - 3.6 km seaward of the outfall. Volatile organic constituents in water samples were analyzed by a standard purge and trap procedure with helium as the purge gas and Tenax GC as the adsorbent. The water samples (70 ml) were purged for 10 min at ambient temperature and the volatile compounds adsorbed on the Tenax were later desorbed by heating the trap and separated on a 183 cm x 6.35 mm I.D. glass column packed with 0.2% Carbowax 1500 on Carbopack. On exiting from the column the mass spectra of the components were recorded. Retention times and mass spectra of compounds present were compared with those of various standards run under identical conditions. The purged water samples, still in the apparatus, were warmed to 50-60°C and purged again for 10 min with the analysis completed as before to detect those compounds having a stronger affinity for water.

RESULTS

FISH DISTRIBUTION AND ABUNDANCE

Species composition and distribution

The total catch of 7470 fish comprised 20 species (Table 3). Juvenile

Pacific herring were the most numerous (39%) and occurred in 14.5% of the catches. Although juvenile chinook salmon were less numerous, they had the highest frequency of occurrence (20.5%). Overall, approximately 98% of the total fish captured were from 6 species: Pacific herring, shiner perch, Pacific sand lance, surf smelt, threespine stickleback, and chinook salmon.

The total catches of fish from each of the 11 sampling sites are shown in Table 4 in order of numerical dominance; a representation of relative abundance for all species at each sampling station is presented in Figure 3. Only two species of fish were captured within 300 m of the sewage outfall: two peamouth chub and one Pacific snake prickleback. Another 2 species (Pacific herring and starry flounder) were captured 600 m from the outfall but at the more distant sites the number of fish species captured rose rapidly; for example, 7 species were caught at 1000 m and 10 species at 2700 m from the outfall. Over all the stations adjacent to the sewage channel, the number of species caught ranged from 2 - 10. In comparison, on the north side of Iona jetty at sites 2, 11, 10 and 9 (which are directly opposite sites 3, 6, 7, and 8 respectively), the number of fish species captured at each site ranged from 8 to 13.

Catch comparisons between sites

An examination of the fish catches between sampling sites was made by applying Analysis of Variance and Newman-Keul's Test to the following groupings of the data: i) all species combined, ii) non-salmonids, iii) salmonids, iv) herring and v) chinook. Chinook salmon was chosen as a category because of the documented fidelity this species has to estuarine intertidal areas during its early sea life and also because of its high frequency of occurrence during our study. The herring data were grouped for testing because of the numerical dominance of this species in the study area. Three comparisons were made of the the five groupings of fish catch data: i) between sites on the south side of the Iona jetty - along the usual effluent dispersal path, ii) between the 7 sites on the south side of the jetty and the 4 sites on its north and relatively effluent-free side, and iii) between the 4 directly opposite sampling sites on the north and south sides of the jetty. The results of these comparisons are shown in Table 5.

A comparison of total catches of fish between all seven sites along the south side of Iona jetty yielded two homogeneous data sub-sets. Catches at site 5 (Fig. 2) were common to both data sub-sets (Table 5), but it is apparent that the lower catches at sites 1 and 3 (Fig. 3, Table 4) within 600 m of the sewage outfall were significantly different ($\alpha = 0.05$) from those at sites 4, 6, 7 and 8 (Table 5).

There was no significant difference between the catches of non-salmonids at the seven sampling sites (Table 5). However, a significant difference was found for salmonid catches (all species combined and for chinook salmon). For both these groupings, catches at sites 1 and 3 were signficantly different from those at site 8 while catches at sites 4, 5, 6 and 7 were similar and resulted in the catches at these sites being common to both data sub-sets.

South jetty vs north jetty catch comparisons

Comparing fish catches at sites on the south side of Iona jetty with catches on the north side, a significant difference was recorded for each of the 5 data groups analyzed (Table 5). Fewer fish were always caught on the south side of the jetty which is typically under direct influence of the sewage effluent. Overall, about 9 times more fish of all species (6717) were captured at the 4 sites on the north side of Iona jetty whereas only 753 were captured from the 7 sites on the south side. Non-salmonid catches totalled 6525 on the north side and were about 10 times more abundant than non-salmonid total catches on the south side (630). Pacific herring comprised much of the non-salmonid catch and the north side - south side distribution of total herring catch was 2522 and 384 respectively. Salmon were 1.5 times more abundant on the north side (total 190) than on the south side (total 125) and chinook salmon comprised most of this catch (141 north, 89 south). It should be noted, moreover, that these comparisons entailed approximately twice the fishing effort on the sewage channel side of the jetty.

ASSOCIATION OF FISH DISTRIBUTION AND WATER CHEMISTRY VARIABLES

Table 6 summarizes water chemistry data obtained at the time of fish capture at each of the 11 sampling sites. Measurements were taken at 0.5 m depth.

It was anticipated that these data would provide not only some relationship between fish presence and levels of the measured variables but also information that would assist in a possible explanation of fish distribution and abundance over the study area. The latter hypothesis was tested using Analysis of Variance and Newman-Keul's Test on the water chemistry data for the same site groupings that were used in the analysis of fish catch data. Comparisons were made for water chemistry values between sites on the south side of Iona jetty and also between all sites on the south side vs all sites on the north side of the jetty. The variables measured were temperature, conductivity, pH, dissolved oxygen, and oxidation-reduction potential.

For the comparison of water chemistry variables between sites along the south side of Iona jetty, significant differences were present for pH and dissolved oxygen. Sites 1, 3 and 4 (all within 1 km of the sewage outfall) had pH values that were significantly lower than those at the more distant sites 5, 6, 7 and 8. Dissolved oxygen concentrations at sites 1 and 3 (within 600 m of the outfall) were signficantly lower than those for sites 5, 6, 7 and 8, but those for site 4 were common to both homogeneous data sub-sets.

Only pH and conductivity were significantly different between sites on the north side (higher values) and the south side of the Iona jetty.

IN-SITU BIOASSAY EXPERIMENTS WITH JUVENILE CHINOOK SALMON

The results of these in-situ experiments are shown in Figure 4 and the associated water chemistry data are presented in Table 7. The ranges in time to 50% mortality of the test fish are variable due, in part, to the inconsistant frequency of observation. Observations were intended to be made on a daily basis and, at those sites where all the fish had died, replicate experiments were to have started. This approach resulted in the running of a number of concurrent replicate bioassays, but the logistics of sampling all sites at the same frequency and the variable occurrence of degraded environmental conditions causing rapid mortality of test fish prevented, on many occasions, a consistent monitoring of fish survival times.

At all distances up to 2.3 km from the sewage outfall, the juvenile chinook salmon frequently died within 24 h and on one occasion 2.7 km distant from the outfall, they died in less than 2 h. However, between 2 and 4 days exposure was required to kill the test fish at sites farther from the outfall including the outermost test site 4.4 km seaward.

The most rapid mortality of the test fish occurred during periods of low dissolved oxygen and in some experiments, carried out between 1.0 km and 2.3 km from the sewage outfall, all the fish died in less than 10 minutes. On July 9, 1980 when numerous wild fish in the sewage channel area were in a "stressed" state and could be easily captured by hand, an in-situ bioassay test carried out at Site 5 (2.2 km from outfall) resulted in the death of 50% of the test fish in less than 2 min and all the fish in 9 min. The dissolved oxygen content of the water at this test site was 0.7 mg L^{-1} during this time.

DISSOLVED OXYGEN DEPRESSION AND FISH MORTALITY

On July 8, 1980 an attempt was made to determine the extent of dissolved oxygen depression during the latter stages of an ebb tide and the start of the following flood tide. Two surveys were carried out: one was between 0650 h and 0903 h, approximately corresponding to the last stages of an ebb tide which was decreasing from a height of 4.6 m at 0155 h to 1.1 m at 0920 h; the second survey was between 0955 and 1200 h when the tide was rising to a height of 4.0 m at 1650 h.

The results of the first and second surveys are shown in Figures 5 and 6, respectively, with annotations in Figure 6 describing the heavy bird predation arising from 'abnormal' fish behavior. For simplicity only dissolved oxygen concentrations recorded at the water surface and the time of the recordings are shown.

During the first survey, which was carried out in calm wind and sea conditions, dissolved oxygen concentrations were especially low at the stations within the sewage channel but increased in a southerly direction across Sturgeon Bank. Water draining from the intertidal flats by the main natural drainage channel contained a relatively higher concentration of dissolved oxygen and, similarly, dissolved oxygen concentration levels at the southern-most sampling

sites (400 to 800 m from the Iona jetty) were greater than those recorded in waters closer to the Iona Jetty. Between 0747 h and 0903 h fish and shrimp were observed exhibiting abnormal behavior, seemingly indicative of stress from low dissolved oxygen. Gulls were capturing juvenile flatfish from the water surface. Three large flounders were captured by dip net and returned to water with higher dissolved oxygen concentrations where they slowly became more active. The area in which these observations of abnormal fish behavior and bird predation were made extended from about 1700 m to 2800 m seaward from the sewage plant outfall.

On the second survey (Fig. 6) which was carried out on the flooding tide, dissolved oxygen concentrations at the end of the Iona jetty were higher than on the earlier survey. However, at 1700 m to 3200 m from the sewage outfall, dissolved oxygen concentrations were generally lower and ranged between 0.6 and 0.9 mg L^{-1}. As on the first survey, fish and invertebrates seemed to be in a stressed state at some sampling sites. Predation by gulls and herons was particularly noticeable about 3200 m from the outfall and also at the confluence of the natural drainage channel and the sewage effluent channel (between 1900 and 2500 m from the outfall). At this confluence a number (<100) of dead fish were seen (most probably sand lance and/or herring) but an estimated thousands of fish and invertebrates (shrimps and mysids) appeared to be stressed, as evidenced by their frequent surfacing behaviour. The fish observed in this stressed state were juvenile sand lance, herring, sculpins, flatfish (mainly starry flounder), shiner perch and stickleback.

Stressed fish were again found on July 9, particularly in the area of the confluence of the natural drainage channel and sewage channel. Gulls and herons were preying on fish and a sample of the natural fish population was easily captured by dip net at a site where 50% of the fish died in an in-situ bioassay experiment within 2 min and all were dead within 9 min.

A limited area of Sturgeon Bank waters south of Iona jetty was examined in more detail during July and August 1981 to determine the changes in dissolved oxygen with tidal state and height. Sampling was carried out on tidal regimes similar to those occurring when stressed fish were observed, namely, low tides of less than 1 m in late morning. Calm weather conditions prevailed during this sampling. Access to the intertidal sandbanks adjacent to the sewage channel was restricted at certain tide heights and accordingly sampling depths (and therefore sample sizes) differed between sampling sites. The results of these preliminary surveys are shown in Table 8 and Figure 7.

Table 8 presents dissolved oxygen data for surface waters grouped by tidal state (ebb, flood) and 1-m increments in tidal height. These results are also shown in the diagrams comprising Figure 7. In illustrating the temporal and spatial distribution of the oxygen content of waters in the sewage channel area, the ranges of dissolved oxygen concentrations used are based on oxygen criteria to protect anadromous and marine fish species, which includes the salmonids (Davis 1975). S ch an assemblage of fish was present in the study area of Sturgeon Bank. The three protection levels specified by Davis are as follows:

> Level A (9.0 mg L^{-1}) - "This level is 1 S.D. above the mean average incipient oxygen response level for the group. The rationale is that few members of a fish population, or fish community, will likely exhibit

effects of low oxygen at or above this level. Level A represents more or less ideal conditions and permits little depression of oxygen from full saturation."
Level B (6.5 mg L^{-1}) - "This level represents the oxygen value where the average member of a species in a fish community starts to exhibit symptoms of oxygen distress .... Some degree of risk to a portion of the fish populations exists at this level if the oxygen minimum period is prolonged beyond a few hours."
Level C (4.0 mg L^{-1}) - "At this level a large portion of a given fish population or fish community may be affected by low oxygen. This deleterious effect may be severe, especially if the oxygen minimum is prolonged beyond a very few hours .... This level should be applied only if fish populations in an area are judged hardy or of marginal significance, or of marginal economic importance and, as such, are dispensible (i.e. in the social or economic sense)".

At water heights between 4 m and 3.1 m during ebb tides (Fig. 7), mean dissolved oxygen concentrations at all sites were greater than the Level C criterion and, apart from the area within 1 km of the sewage outfall, were between the level B and level A criteria (Table 8). With further progression of the ebb tide to 3.0 - 2.1 m, waters in the same area had lower dissolved oxygen values and, at sites 1-5 within 2000 m of the sewage outfall, values were below the level C criterion.

The extent of this oxygen depression in the study area increased seaward with progression of the ebb tide (2-1.1 m height). However, the oxygen deficient waters lateral to and extending southerly from the channel also decreased as waters drained from the intertidal zone. In those areas having sufficient depth to be accessed by boat, dissolved oxygen concentrations were all below the level B criterion of Davis (1975). At the start of the flood tide (1.1-2.0 m height) there was an elevation in the level of dissolved oxygen at the site 1000 m from the sewage outfall and within the effluent channel. Farther seaward, oxygen concentrations were below the level C criterion but rose at more distant sites to between levels B and C. The relatively higher dissolved oxygen content at low tide in waters proximal to the sewage outfall could be related to the aeration of sewage cascading a greater distance down a weir into the effluent channel, compared with high tide. As the flood tide progressed (2.1-3.0 m), waters containing higher concencentrations of dissolved oxygen began to immerse the more seaward parts of the study area.

A time series of vertical profiles of dissolved oxygen concentration further illustrates the changes which occurred during states of the tide and are shown in Figure 8 (derived from data in Table 9). The vertical profiling was carried out at a site about 3.6 km from the sewage outfall and within the effluent channel. The profiles revealed that the depression of dissolved oxygen was variable over the 2.5 m depth.

During the surveys to monitor levels of dissolved oxygen in the waters overlying Sturgeon Bank in 1981, we again noticed the predation of fish by birds, as in 1980. These bouts of predation seemed to be most intense during warm, calm weather on ebb tides and the start of flood tides. The presence of fish close to the water surface appeared to facilitate avian predation. Concurrent recordings of dissolved oxygen in areas where bird predation was occurring indicated that low levels were, at the least, contributing to the

stress of the fish which was typified by the surfacing behavior, a common response to hypoxia. Often the fish would remain at the water surface, breaking the surface film and becoming very easy to capture. After this activity fish frequently sank passively into deeper water, or if close to shore, entered extremely shallow water where they became partially exposed to air.

The locations of bird predation extended from near the outfall and along the length of the effluent channel and further into Georgia Strait (> about 5 km). However, the most frequent observations of predation occurred around the confluence of the large natural drainage channel and the effluent channel (about 2.2 km from the sewage outfall). At low tide, dead fish (especially starry flounders) were found to be widespread over the intertidal zone south of the Iona jetty. The area examined was about 2.0-4.4 km from the outfall. The highest concentration of dead fish occurred close to the junction of the natural drainage and effluent channels: on July 17, 1981, in a 30 m x 200 m area, 307 flatfish, 12 herring and 8 crabs were found dead, and appeared to be freshly killed (most were neither decayed nor partially eaten).

ORGANIC CONTAMINANT ANALYSES CONDUCTED BY RADIAN CORPORATION

Fish muscle tissue

The composite extract prepared from muscle tissue of starry flounders taken at site SB-1 approximately 1 km seaward of the sewage treatment plant outfall (Fig. 1) in August 1978 contained a total of 17 compounds (Table 10) comprising a number of phenols, several persistent chlorinated hydrocarbon pesticides, and the polynuclear aromatic hydrocarbon naphthalene. The identifications are considered tentative (Radian Corporation, 1979) because the concentrations were in most cases too low to permit confirmation by GC-MS, which is about three orders of magnitude less sensitive to chlorinated organics than is GC-HECD. The compounds for which identity was confirmed by GC-MS in the SB-1 flounder extract cleaned up by Florisil columns in later work by Radian Corporation (1980) were 4,4'-DDE, 4,4'-DDT and naphthalene.

In further work by Radian Corporation (1980) to specifically search for and confirm the identity of PCB's in fish tissues, PCB's were found in extracts composited from the flounder captured at sites SB-1 and SB-2 (Fig. 1) in August and November, 1978, and in the extract composited from juvenile salmon captured at site SB-2 in the August sampling. PCB concentrations in flounder were higher in the August sample than in the November sample at the Sturgeon Bank (SB) sites; the PCB concentration in juvenile salmon was considerably lower by comparison (Table 11). The PCB concentration in flounder from the control site on Roberts Bank was below the limit of confident identification but may have been of the order of 1-2 ppb wet weight.

Unchlorinated Iona sewage

The composite sample of three unchlorinated grab samples from Iona Island sewage treatment plant, collected at weekly intervals in November 1979 and analyzed for organic contaminants by Radian Corporation (1980), contained

phenolic compounds and persistent chlorinated hydrocarbon pesticides similar to that found in the SB-1 starry flounder muscle extracts (Table 10). Phenol was the only compound whose identity was confirmed by GC-MS analysis.

ORGANIC CONTAMINANT ANALYSES CONDUCTED AT THE WEST VANCOUVER LABORATORY

Sewage effluent receiving waters: volatile organic compounds

The samples of surface water collected at seven sites within the sewage channel at distances from 0 to 3.6 km from the outfall on July 29, 1981, and analyzed for volatile organic compounds by GC-MS using the purge and trap method are listed in Table 12. Not all compounds were present in those samples collected at the more distant stations. The compounds identified (Table 12) comprise a series of chlorinated C_1 and C_2 hydrocarbons, some aromatic hydrocarbons (benzene, toluene, xylene) and a miscellaneous group of compounds (ethers, ketones, n-butanol). Those substances present in highest concentration in a sample collected at the outfall included chloroform (82 ppb), methyl isobutyl ketone(40 ppb), toluene (92 ppb) and tetrachloroethylene (68 ppb). These compounds were quantified in the surface seawater samples by preparation of a standard containing the four substances at known concentration and analyzing, via the purge and trap technique, seawater samples spiked with the standard mixture. In general, the concentration of the compounds tended to be less at greater distances from the outfall, as is illustrated for the toluene and tetrachloroethylene (Figure 13). The concentration of tetrachloroethylene at a station approximately 2 km from the source may be anomalously high or representative of the heterogeneous distribution of effluent in the process of mixing and dispersing in the receiving waters. At the farthest stations, about 3.6 km from the sewage outfall, methyl isobutyl ketone was no longer detectable while the concentrations of the other three volatiles varied in the range 15 - 30 ppb.

Contaminants in fish tissues and non-volatile organics in receiving water

Table 13 lists 15 organic contaminants identified in samples of starry flounder, staghorn sculpin, shiner perch and receiving water collected from Sturgeon Bank in August 1981. The only chlorinated compound identified was dichloroanisole, which was present in both flounder and sculpin. The only compound common to all types of samples analyzed was phenylacetic acid.

DISCUSSION

FISH DISTRIBUTION AND ABUNDANCE

Very little published information is available on fish utilization of the sandflats comprising Sturgeon and Roberts Banks in the estuary of the Fraser

River. It has only been in recent years that studies have attempted to quantify fish use of these intertidal areas located on the seaward reaches of the Fraser River delta (Greer et al. 1980; C.D. Levings pers. comm.; Levy and Northcote 1982; Levy et al. 1982) More extensive work carried out recently (C.D. Levings pers. comm.) provides additional comparative data pertinent to the present study. Between March 1980 and July 1981, a comparative assessment was made of fish populations using three low-tide habitats or refuges on the "outer" estuary of the Fraser River. One habitat is vegetated largely by eel grass and located on Roberts Bank on the southern limits of the estuarine delta; another is an unvegetated sandy area south and adjacent to the middle arm of the Fraser River and, the third, an unvegetated sandy area receiving sewage effluent (the seaward end of the sewage effluent channel from the Iona Island sewage treatment plant). The latter two low-tide refuges are on Sturgeon Bank. On Roberts Bank, 55 species of fish have been found to use the low tide refuge annually, whereas 25 species were captured in the sandflat refuge on middle Sturgeon Bank and 27 species in the smaller refuge receiving sewage and located on the northern part of Sturgeon Bank. At each of the low-tide refuges, as in the study area we sampled, juvenile herring were numerically dominant. Juvenile chinook salmon also were the numerically dominant salmon species but only at the Sturgeon Bank capture sites. The essential significance of these findings is that the intertidal areas of the "outer" Fraser River estuary are used by large numbers of fish at low and high tide and, accordingly, these populations may be affected by any environmental degradation of these habitats.

Sampling of the low-tide refuge receiving sewage effluent (Levings, pers. comm.) and the present high tide sampling during the same time of the year (May 26 - July 2, 1980) provides comparative data on fish presence and utilization of similar areas of the effluent receiving waters but at different states of the tide. At high tide 20 species of fish were captured but only 12 species were captured in the low-tide refuge at the outer end of the sewage channel (Levings, pers. comm.). As was the case for the high tide sampling, juvenile Pacific herring were most abundant in the low tide refuge comprising 29.8% of the catch followed in descending order of abundance by starry flounder (22.4%), chinook salmon (12.7%), shiner perch (7.4%), and three-spine stickleback (4.9%), with chum salmon, surf smelts, peamouth chubs, largescale suckers and Pacific snake pricklebacks comprising the remaining 1% of the catch. As at high tide in the present study, juvenile herring had a relatively low frequency of occurrence in the low tide catches (10.8%), no doubt reflecting the schooling nature of this fish. In contrast, juvenile chinook salmon comprised only 3.1% of the high tide catches in this study but had the highest frequency of occurrence, being captured on 20.5% of the occasions when fish of any species were captured (Table 3). At low tide on the other hand, juvenile chinook comprised 12.7% of the catch but had a lower frequency of occurrence (6.5%). It seems apparent, therefore, that the widespread distribution of this salmon species and its presence within the sewage effluent channel provides evidence that contact with sewage effluent is very likely in this region of Sturgeon Bank.

An examination of the residency of this species in relation to effluent dispersal would be desirable but difficult to accomplish within the study area because it is open to recruitment of chinook from the Fraser River during downstream migration or from chinook residing in other areas of Sturgeon Bank. A study on fish residency would, however, yield information on the exposure which these economically valuable fish would receive to municipal wastes from

the Iona Island sewage treatment plant. There is, however, sufficient information from other studies in the Fraser River estuary (D.F.O. unpublished data, Levy et al. 1982), studies in the Somass River estuary at Port Alberni and, more recently, the Campbell River estuary (C.D. Levings pers. comm.), that suggests a relatively long residency (weeks to months) of juvenile chinook rearing in southern British Columbia estuarine waters. In addition, juvenile chinook salmon appear to have a higher fidelity for nearshore estuarine areas than do some of the other salmon species (Levy et al. 1979). Thus, this particular salmon species is perhaps most at risk from habitat degradation in the intertidal zone because of its behavioral ecology. Juveniles of pink, chum, sockeye and coho salmon were also captured at high tide but in very low numbers compared to juvenile chinook salmon. Excluding chinook juveniles, chum salmon were the next most numerically dominant salmonid within the high tide catches (Table 3), whereas at low tide (C.D. Levings, pers. comm.) only chum salmon were captured in addition to chinook salmon. Juvenile chum salmon also have been found to have a long utilization period in nearshore estuarine waters (Levy et al. 1979) and the present results support these findings.

To determine if proximity to the source of sewage effluent and location along the Iona jetty influenced catches of fish the data were grouped for analysis. A preferable analysis would have treated each species and sampling occasion separately but insufficient data prevented this. As mentioned previously only two species of fish were treated separately, juvenile herring and chinook salmon, while data for all species, non-salmonids, and salmonids, comprised three other data groupings. It is recognized that such groupings are somewhat arbitrary despite the findings that at least three species of salmon have been shown to behave similarily in response to pulpmill effluent (unpublished data). Accordingly, the statistical separation of information must be considered, at least for combined datasets, in relation to those shortcomings. The catch data for the study period were combined due to the short time period over which sampling occurred (it was particularly selected to encompass the main period of intertidal ulitization by juvenile salmon in estuarine waters).

The fish catch data for all sites along the south side of the Iona jetty indicated that intertidal utilization was reduced with proximity to the effluent outfall. Salmon did not use the intertidal area of Sturgeon Bank within about 1000 m of the sewage outfall and a transition zone extended to about 3.6 km seaward after which catches were significantly higher. Although this trend was not apparent for the 'non-salmonid' and 'herring' data sets it was, in part, revealed for the 'all species combined' set. The presence of fewer fish with proximity to the sewage outfall and the absence of salmon cannot be entirely explained. It is known that the effluent is toxic to fish (96h LC50 ca. 45%; Martens and Servizi 1976) and that it exerts a high oxygen demand both directly, and indirectly due to the demand of settled organic matter which has formed sludge deposits (B.C. Research 1975, 1977). Both features could influence the distribution of fish within the sewage channel. Additional complicating factors such as the attraction of fish to outfalls and effluents and the avoidance of fish to municipal wastes (Alexander et al. 1977) may also affect fish distribution. Notwithstanding these additional complexities, the analysis of water chemisty data revealed that the separation of sampling sites with similar pH and dissolved oxygen concentrations was similar to the separations obtained for 'salmon', 'all salmonid species', and 'all species combined' catch data sets. The results support the contention that some of the

measured levels of water variables could have affected the distribution of the fish. While it is unlikely that pH affected the distribution of fish (range 7.05 ± 0.03 at 300 m and 8.02 ± 0.30 at 4.4 km from the outfall), dissolved oxygen concentrations close to the outfall (5.66 ± 1.82 mg L^{-1}, 300 m; 4.94 ± 1.28 mg L^{-1}, 600 m) were generally below the level B criterion proposed by Davis (1975). At these levels of dissolved oxygen, mixed fish populations of marine and anadromous species including salmonids would be expected to experience oxygen distress. Such an effect possibly associated with some toxic effect of the effluent could have prevented full use of the intertidal area close to the sewage outfall.

In contrast to the fish distribution pattern recorded for the southern side of the Iona jetty, significantly greater catches were obtained on the northern side. The catches at the most shoreward site (site 2) on the northern side of the jetty opposite to site 3 indicated that, at high tide, fish used the high intertidal area. The equivalent area on the south side was underutilized. To exemplify this point, a total of 570 fish comprising 10 species (including chinook, chum and pink salmon) was recorded at site 2 in marked contrast to the total catch of 12 fish comprising two species (Pacific herring, starry flounder) recorded at site 3. Similar marked differences in the catches at other sites along the north side of Iona jetty compared with catches on the south side lend further support to the conclusion that fish use of the intertidal area receiving sewage effluent was significantly reduced. However, the influence of other factors cannot be ignored. Significantly higher values for conductivity and pH on the north side of the jetty indicates that different water masses could have been sampled which, of course, could have been characterized by different densities and communities of fish. It should be noted, however, that species composition was very similar on both sides of the Iona jetty (Table 4).

Thus it is apparent that fish habitat on the south side of the Iona jetty was underutilized and was impaired due to the discharge of sewage effluent, at least during the period May to July 1980. Those underutilized regions are within the area which has been described as severly degraded, based upon earlier studies of aquatic invertebrates, sediment chemistry, and bacteriology (B.C. Research 1973, 1975, 1977). Furthermore, it is evident from water chemistry analyses, in-situ bioassay experiments, and observations of natural populations of fish that, at certain tidal states and climatic conditions, fish are severely affected by the discharge of sewage effluent into their habitat.

FISH SURVIVAL AND DISSOLVED OXYGEN DEPRESSION

The in-situ bioassay results showed that fish could not survive prolonged exposure to the waters along the sewage effluent channel at distances up to 4.4 km from the outfall. The fish held 4.4 km from the outfall survived longer than those which were held in cages closer to the outfall; it was expected that survival would improve with distance from the outfall due to the dilution effect provided by natural drainage of the intertidal banks into the sewage effluent channel at low tide and the onshore movement of Georgia Strait waters on the flood tide. The most severe oxygen depletion occurred at low

tide, however, when dilution was minimal. Similarly, on flood tides the more distant sites would be immersed in 'fresher' waters of higher oxygen content earlier than those sites closer to the outfall. While the results of fish survival and water analyses support this expected test fish survival and water movement pattern, we did not expect such an extensive zone within which fish died rapidly. The toxicity of the effluent (Martens and Servizi 1976) combined with the extremely low dissolved oxygen concentrations were probably responsible for the often very rapid death of the juvenile chinook. Chapman (1939) found that the minimum concentration of dissolved oxygen required to maintain chinook salmon in 'normal' condition was greater than 3.5 mg L^{-1} and Whitmore et al. (1960) noted that juvenile chinook salmon exhibited avoidance reactions to dissolved oxygen concentrations as low as 4.5 mg L^{-1}. The lowest dissolved oxygen concentrations recorded during the course of the in-situ bioassay tests were below the minimum levels reported by Chapman (1939) and by Whitmore et al. (1960) and also were below the level C criterion of Davis (1975) which specifies that at and below this criterion "a large portion of a given fish population or fish community may be affected by low oxygen." It is not surprising, therefore, that even at 2.2 km from the outfall and when the dissolved oxygen concentration was 0.7 mg L^{-1} 50% of the fish died within 2 minutes. The cause of this oxygen depletion is likely to be the high oxygen demand of the effluent coupled with the demand of the sludge beds in the severely degraded intertidal zone close to the sewage outfall. Within the degraded zone the oxygen consumption rates of benthic deposits are high and typical of organically polluted environments. These values contrast with those for sites on the north side of the Iona jetty and at more seaward locations along its southern edge (B.C. Research 1975, 1977).

The observations of apparently stressed fish and of dead fish, together with recordings of low dissolved oxygen concentrations at various tidal states provide further evidence substantiating the opinion that the waters over Sturgeon Bank receiving sewage can be detrimental to fish. Our results and observations support the following scenario of events:

The waters flowing on rising tides onto the sandflats comprising Sturgeon Bank are generally high in dissolved oxygen but due to the discharge of sewage from the Iona Island sewage treatment plant a progressive reduction in dissolved oxygen occurs over the southern part of the bank between the Iona jetty and the middle arm of the Fraser River. During calm weather and the warmer part of the year the water on Sturgeon Bank is markedly stratified with freshwater overlying more saline waters. During tidal submersion of the bank the oxygen demand of the effluent and sludge beds in the vicinity of the outfall progressively reduce the dissolved oxygen in the receiving waters. On an ebb tide there is a seaward movement of oxygen deficient waters adjacent to the Iona jetty. While water movement is essentially southwesterly into Georgia Strait, drainage channels which traverse the intertidal flats convey waters into the sewage channel which emerges as the ebb tide progresses. At low tide, there is a net seaward movement of waters of low oxygen content due to the continuous influx of sewage effluent; however, relatively higher dissolved oxygen concentrations occur close to the discharge location most probably due to the aeration of the effluent cascading down the weir at the outfall (the aeration capability being greater at low tide compared with high tide due to the differences in tidal heights). The dissolved oxygen depression extends more than 4.4 km into Georgia Strait but tends to be

restricted to a zone close to the Iona jetty at low tide. Organisms encountering these oxygen deficient waters then become stressed or killed.

The results of the high tide fish sampling and the results of the low tide refuge study (C.D. Levings, pers. comm.) on Sturgeon Bank revealed widespread fish use of the area receiving sewage. Levings found that juvenile salmon and other fish used the seaward section of the sewage channel at low tide. The fish were, therefore, found in locations where they could become immersed in waters containing sewage and with reduced levels of dissolved oxygen. This situation is further compounded by the seaward transport of fish along drainage channels into the oxygen deficient waters of the sewage channel. At tidal heights below about 2 m one of the main drainage channels over Sturgeon Bank becomes exposed (Fig. 2). Although water flowing down this channel tends to be relatively high in dissolved oxygen, the concentrations become lower with proximity to the junction with the sewage channel. At very low tides the channel almost empties of water and it is significant that the junction of this channel with the sewage channel, and locations farther seaward, were the sites of active bird predation, fish stress and mortality. The indication is that the fish residing in the natural drainage channels become transported into the oxygen deficient waters of the sewage effluent channel where they may be killed directly, indirectly due to predation, or otherwise stressed. Any toxic effects of the effluent would probably be intensified under these hypoxic conditions. It is noteworthy that species with different behavioral ecologies were killed.Bottom dwelling (e.g. flat fish) and pelagic (e.g. herring) fish were in an apparently stressed state perhaps indicating that oxygen depletion occurred throughout the stratified water column. Davis (1975) and Tsai (1975) give examples of fish behavior in response to hypoxia and it appears that the response of many fish is to rise to the water surface. By moving to the water surface the fish become easy prey for avian predators. The congregations of herons and gulls on Sturgeon Bank were usually around areas of oxygen deficient waters where fish were found at the water surface; the feeding success of the birds appeared to be high.

Many dead flatfish (mainly starry flounder) of different age classes were found on the intertidal sandflats of Sturgeon Bank. The widespread and frequent avian predation on fish species in this area show that the effect of discharging sewage into the outer estuary of the Fraser River has a significant effect on fish communities. Past studies on the impact of the sewage from the Iona sewage treatment plant described an area of degradation confined to within about 2 km from the outfall (e.g. B.C. Research 1973, 1975, 1977). The findings of our study reveal a larger area of impact and one that probably affects a substantial portion of the fish productivity of the estuary. The mortality of different age classes of starry flounders (a species which makes extensive use of the intertidal areas of the Fraser estuary) on a regular basis during the summer period could result in successive shoreward migrations followed by mortality of the fish to the extent that their stocks could be severely depleted. It may be coincidental, but the start of declining catches of flatfish in the fishing area adjacent to the Fraser River since 1965 (K. Ketchen pers. comm.) coincides with the discharge of sewage effluent from the Iona Island sewage treatment plant which started operating about 1964.

Although one of the effects of discharging sewage effluent into the intertidal area of Sturgeon Bank has been to reduce dissolved oxygen

concentrations and thereby affect fish survival and possibly habitat use, a number of other effects on the resident and transient biological communities have been noted. Studies have been carried out on the effect on the clam Macoma balthica, a major food item of flatfish in the area (McGreer 1979), and on the contamination of crabs, flatfish, salmon and clams by heavy metals (EVS Consultants Ltd. 1979).

ORGANIC CONTAMINANT ANALYSES

The sample of starry flounders taken on Sturgeon Bank (site SB-1) in August 1978 had been found to contain low levels of undefined chlorinated organics in an earlier study (Radian Corporation 1979). In further studies (Radian Corporation 1980) the SB-1 flounder extract was subjected to gel permeation chromatography using the cleanup procedure of Tindle and Stalling (1972). Analysis of the lipid-free extracts indicated the presence of trace levels of a series of persistent chlorinated hydrocarbon pesticides (Table 10). Some of these, especially the DDT-related compounds, remain in the environment for long periods and can become redistributed in the environment through atmospheric fallout. For example, loadings of DDT-related compounds in the Great Lakes via the airborne route has been documented (Eisenreich et al. 1981). Most of the pesticides shown in Table 10 are of the type that are airborne contaminants. There remains, therefore, some uncertainty about the contribution of persistent chlorinated hydrocarbon pesticides from the Iona Island sewage treatment plant in the contamination of these fish since the whole area of the Fraser River delta may have also become contaminated via the atmospheric fallout pathway. Another route to the estuary of these pesticide compounds could be via runoff from the agricultural areas of the Fraser River valley.

The phenol and chlorinated phenols identified in the flounders likely arise from the household and domestic use of such compounds as antiseptics and wood preservatives. Their sources may also include hospitals and research laboratories located in the central and western parts of the municipality of Vancouver.

The compounds identified (Radian Corporation 1980) in the unchlorinated sewage samples (Table 10) were similar to those identified in flounder samples taken on Sturgeon Bank about fifteen months earlier (Radian Corporation 1979). Naphthalene and some additional phenols were present in the sewage but these compounds were not quantified. From the close resemblance between the list of compounds identified in the sewage and that present in the flounders (Table 10), it can be concluded that the Iona Island sewage treatment plant wastewater played at least some role in the contamination of flounders on Sturgeon Bank.

The PCB's identified in flounder and juvenile chinook tissue samples from Sturgeon Bank and flounder tissue from Roberts Bank had GC composition patterns similar to the Aroclor 1254 standard. The highest levels of PCB's were recorded in starry flounders taken in August, 1978, at stations SB-1 (640 ppb) and SB-2 (660 ppb) which are approximately 1 km and 3 km, respectively, seaward of the outfall. In comparison the PCB levels in juvenile chinook salmon were relatively low at SB-2 (Table 11). The sample of starry flounder collected in

November 1978, on the other hand, contained 167 ppb in the SB-1 sample whereas the corresponding SB-2 sample did not contain PCB's. It is possible that the population sampled in August had been resident in the area longer than that sampled in November. The PCB levels in juvenile chinook and starry flounder could be directly related to differences in their periods of residency in the receiving waters as well as generally related to their physiological and behavioural ecologies. The levels of PCB's present in the flounder muscle tissue and in salmon, however, may be regarded as high since they are within the range of muscle tissue levels found in similar species from Commencement Bay, Puget Sound, which has recently become distinguished as one of the ten most contaminated waste sites in the United States (Malins 1981; Kopenski 1982).

In the list of volatile organic contaminants identified in receiving water samples taken at varying distances from the outfall (Table 12), chloroform and methylene chloride are haloforms whose formation during chlorination of municipal drinking water is well known (see for example Norin and Renberg 1980). Tetrachloroethylene is a drycleaning solvent and trichloroethylene is used in degreasing operations in machine shops. Benzene, toluene and the xylenes are also widely used as solvents and as components of gasoline and fuels. Methyl isobutyl ketone is used as a solvent. This compound is more water soluble than the other substances and was noted to dissipate more rapidly with distance from the outfall. The remaining three compounds listed in Table 11 (ether, n-butanol and ethylene glycol monomethyl ether) also find limited use as solvents.

Toxicity levels of chloroform, trichloroethylene and tetrachloroethylene to marine fish have been investigated by Pearson and McConnell (1975); the 96h LC50 to dabs (flatfish) were estimated as 28, 16 and 5 mg L^{-1}, respectively. An ambient water quality criterion of 28,900 µg L^{-1} has been established to protect freshwater aquatic life from acutely toxic effects of chloroform (Anon 1980). Levels below 1240 µg L^{-1} are considered not to give rise to chronic toxicity effects in freshwater species. However, no criteria have been established to date for saltwater species because of a lack of information. The maximum bioconcentration factor between sea water and tissue samples was found to be about 100-fold for trichloroethylene and tetrachloroethylene (Pearson and McConnell 1975).

Some starry flounders, a staghorn sculpin and a shiner perch were taken in August 1981 in the area of the outfall and the organic compounds identified in tissue extracts are shown in Table 13. Dichloroanisole was present in flounder and sculpin extracts. This compound could be derived from contaminated sediments where dichlorophenol may have been converted by biological methylation into the corresponding anisole. Such conversions by bacteria and fungi are known to occur (see Lech et al. 1978). The dichlorophenol might have originated from household use as an antiseptic, as a breakdown product of 2,4-D used as a herbicide or as a result of chlorination of phenol during the disinfection of sewage in the summer months. Studies in Finland have shown the presence in lake sediments of 2,6-dichlorophenol, which has been found to be one of the most persistent of the chlorinated phenols (Salkinoja-Salonen et al. 1981; Paasivirta 1981). This compound appears to be derived from the partial breakdown in the receiving environment of more highly chlorinated phenols formed during pulp bleaching operations. It is noteworthy that this compound predominated in the "cleanest" lakes studied in Finland. The compound α-terpineol is widely used in household cleansing formulations because

of its germicidal properties. Its presence in municipal sewage is not therefore surprising. Most of the other compounds identified are aromatic acids which probably arise from protein breakdown and their presence, and that of the drug caffeine, have been reported in other studies on municipal sewage (Garrison et al. 1976). Starry flounders taken at stations SB-1 and SB-2 in 1978 contained PCB's at levels as high as 660 ppb (Radian Corporation 1979 see Table 11). Analysis of tissue samples conducted in the West Vancouver Laboratory did not include the specialized destructive cleanup procedure used in PCB analysis and the presence of PCB's in those samples remains unknown.

In conclusion, the present findings indicate contamination of receiving waters on Sturgeon Bank and organisms utilizing this intertidal habitat. In light of the importance of the Fraser River's fisheries resources and the modest knowledge of contaminant levels and their interaction within this system, concern and well conceived research appear to be of foremost importance.

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REFERENCES

Alexander, D.G., K.J. Supeene, B.C. Chu, and H.D. Maciorowski. 1977. The lethal and sublethal effects of secondary-treated sewage effluent on various fish and invertebrates. Fish. Mar. Serv. Tech. Rep. 709. vi + 21 p.

Anon. 1980. Ambient water quality criteria for chloroform. United States Environmental Protection Agency. EPA 440 15-80-033.

B.C. Research. 1973. Environmental studies at Iona Island. Prepared for the Greater Vancouver Sewerage and Drainage District. 52 p.

B.C. Research. 1975. Environmental studies at Iona Island. Report No. 2. Prepared for the Greater Vancouver Sewerage and Drainage District. 162 p.

B.C. Research. 1977. Environmental Studies at Iona Island. Report No. 3. Prepared for the Greater Vancouver Sewerage and Drainage District. 23 p.

Beak Consultants Ltd. 1980. Sample analysis to determine mercury levels from crabs off the Fraser River. Prepared for the Department of Fisheries and Oceans, Canada. 10 p.

Brown, D.A., C.A. Bowden, K.W. Chatel and T.R. Parsons. 1977. The wildlife community of Iona Island jetty, Vancouver, B.C., and heavy metal pollution effects. Environmental Conservation 4(3): 213-216.

Cain, R.J. and L.G. Swain. 1980. Fraser River Estuary Study, Water Quality: Municipal effluents. Ministry of Environment, Victoria, B.C. 101 p.

Chapman, W.M. 1939. Effects of decreased oxygen supply in sockeye and chinook salmon. Trans. Am. Fisheries Soc. 69: 197-204.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species. A review. Fish. Res. Board Can. 32: 2295-2332.

Dunn, B.P. and H.F. Stich. 1976. Monitoring procedures for chemical carcinogens in coastal waters. J. Fish. Res. Board Can. 33: 2040-2046.

E.V.S. Consultants Ltd., 19079. Identification of heavy metals in organisms within an area of the Fraser River estuary receiving a major municipal industrial and stormwater discharge. Prepared for the Department of Fisheries and Oceans, Canada. 74 p.

Eisenreich, S.J., B.B. Looney and J.D. Thornton. 1981. Airborne organic contaminants in the Great Lakes ecosystem. Environ. Sci. and Technol. 15: 30-38.

Garrison, A.W., J.D. Pope and F.R. Allen. 1976. GC/MS analysis of organic compounds in domestic wastewaters. In "Identification and Analysis of Organic Pollutants in Water" edited by L.H. Keith, pub. by Ann Arbor Science. p. 517-556.

Greer, G.L., C.D. Levings, R.Harbo, B. Hillaby, T. Brown and J. Sibert. 1980. Distribution of fish species on Roberts and Sturgeon Banks recorded in seine and trawl surveys. Can. MS. Rep. Fish. Aquat. Sci. 1596. 51 p.

Junk, G.A. and C.S. Ford. 1980. A review of organic emissions from selected combustion processes. Chemosphere 9: 1878-230.

Kopenski, R.P. 1982. Rehabilitation of Commencement Bay (WA) through Superfund. Coastal Ocean Pollution Assessment News 2(1): 2-3.

Lech, J.J., A.H. Glickman and C.N. Statham. 1978. Studies on the uptake, disposition and metabolism of pentachlorophenol and pentachloroanisole in rainbow trout (Salmo gairdneri). In Pentachlorophenol: Chemistry, Pharmacology and Environmental Toxicology. Ed. K. Rauga Rao. Pub. Plenum Press, New York. p. 107-113.

Levings, C.D., G. Otte and J. Longmuir. Analyses of macro-invertebrate communities influenced by sewage on the Fraser River estuary, British Columbia. Unpublished manuscript.

Levy, D.A. and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39: 270-276.

Levy, D.A., T.G. Northcote and R.M. Barr. 1982. Effects of estuarine log storage on juvenile salmon. Westwater Research Centre, The University of B.C. Tech. Rept. 26. 101 p.

Levy, D.A., T.G. Northcote and G.J. Birch. 1979. Juvenile salmon utilization of tidal channels in the Fraser River estuary, British Columbia. Westwater Research Centre, The University of B.C. Tech. Rept. 23: 70 p.

Malins, D.C. 1981. Concentration of organic toxicants in salmon, cod, and sole from Puget Sound. Coastal Ocean Pollution Assessment News 1(4): 52-53.

Martens, D.W. and J.A. Servizi. 1976. Acute toxicity at three primary sewage treatment plants. Int. Pac. Salmon Fish. Comm. Prog. Rept. 33: 20 p.

McGreer, E. 1979. Studies of the bivalve, (Macoma balthica) (L.), on a mudflat receiving sewage effluent and on an unpolluted mudflat, Fraser River estuary, British Columbia. M.Sc. Thesis. Institute of Oceanography, University of British Columbia. Vancouver,B.C. 99 p.

Norin, H. and L. Renberg. 1980. Determination of trihalomethanes (THM) in water using high efficiency solvent extraction. Water Res. 14: 1397-1402.

Otte, G. and G.D. Levings. 1975. Distribution of macro-invertebrate communities on a mudflat influenced by sewage, Fraser River estuary, British Columbia. Fish. Mar. Serv. Res. Dev. Tech. Rep. 476: 63 p.

Parsons, T.R., C.A. Bawden, W.A. Heath. 1973. Preliminary survey of mercury and other metals contained in animals from the Fraser River mudflats. J. Fish. Res. Board Can. 30: 1014-1016.

Paasivirta, J. 1981. Enrichment of chlorobleaching residues in food chain. Nordforsk Milovardsekreteriet Publication No. 1, 187-195.

Pearson, C.R. and G. McConnell. 1975. Chlorinated C_1 and C_2 hydrocarbons in the marine environment. Proc. R. Soc. Lond. B. 189: 305-332.

Radian Corporation. 1979. Identification by GC-MS analyses of halogenated organics and PCB's in tissues of selected aquatic organisms. Prepared for the Department of Fisheries and Oceans, Canada. 46 p.

Radian Corporation. 1980. Analysis of organics in sewage. Prepared for the Department of Fisheries and Oceans, Canada 41 p.

Rawn, A.M., C.G. Hyde and J. Oliver. 1953. Sewerage and drainage of the Greater Vancouver area, British Columbia. Vancouver and Districts Joint Sewerage and Drainage Board. 278 p.

Sallzinoja-Salonen, M., M.-L. Saxelin, J. Pere, T. Jaakkola, J. Saarikoski, R. Hakulinen and O. Koistinan. 1981. Analysis of toxicity and biodegradability of organochlorine compounds released into the environment in bleaching effluents of kraft pulping. In. Advances in the Identification and Analysis of Organic Pollutants in water. Volume 2. Ed. L. H. Keith, Pub. Ann Arbor Science, p. 1131-1164.

Tabata, S., L.F. Giovando and D. Devlin. 1971. Current velocities in the vicinity of the Greater Vancouver Sewerage and Drainage District's Iona Island outfall - 1968. Fish. Res. Board Can. Tech. Rep. 263: 110 p.

Tanner, G., G. Trasolini and L. Nemeth. 1973. A study on wastewater characteristics of Greater Vancouver sewage treatment plants and major sewers. Environmental Protection Service, Environment Canada. Tech. Rep. EPS 5-PR-73-11: 223 p.

Tindle, R.C. and D.L. Stalling. 1972. Apparatus for automated gel permeation cleanup for pesticide residue analysis. Anal. Chem. 44: 1768-1773.

Tsai, C. 1975. Effects of sewage treatment plant effluents on fish: a review of literature. Chesapeake Research Consortium Incorporated. Publication 36: 229 p.

Vermeer, K. and D.B. Peakall. 1979. Trace metals in seaducks of the Fraser River delta intertidal area, British Columbia. Marine Pollut., Bull. 10: 189-193.

Whitmore, C.M., G.E. Warren and P. Doudoroff. 1960. Avoidance reactions of salmonids and centrachid fishes to low oxygen concentrations. Trans. Am. Fisheries Soc. 89: 17-26.

Table 1. Annual net wholesale value associated with Fraser River salmon stocks (1981 value).

Species	Escapement	Total catch[3]	Total Canadian commercial and native food fish catch	Annual net wholesale value: Canadian catch[4]
Chinook	65,938[1]	645,951	310,057	6,213,542
Chum	442,570[1]	462,190	378,996	5,669,780
Coho	64,316[1]	247,585	113,888	1,170,769
Pink	884,193[2]	2,450,007	1,592,504	7,771,419
Sockeye	1,296,945[2]	4,739,829	2,891,295	32,671,633
Totals:	2,753,962			53,497,143

1. Department of Fisheries and Oceans - unpublished data

2. International Pacific Salmon Fisheries Commission: annual reports 1969 to 1978. (Pink salmon estimates have been averaged over all years to provide an annual estimate).

3. Includes Canadian commercial, sport and native Indian catch and American interceptions. Estimated from S.E.P. Production Distribution Tables for Fraser River stocks.

4. Barclay, J.C. 1977. Estimation of Commercial Fishery Benefits and Associated Costs for the National Income Account. In Appendix 2 of the "Economic Rationale for the Salmonid Enhancement Program". Department of Fisheries and Oceans, unpublished data. Native food fish catches are valued at commercial prices.

Table 2. Total value and catch (metric tons) of non-salmonid fish and invertebrates in fisheries statistical areas 29 A, B, and C (Fraser River and estuary).

SPECIES	CATCH	VALUE ($ 1981, 000)
Crab	207.3	606.5
Shrimp	67.9	183.9
Sole	9.4	10.7
Rockfish	1.5	1.3
Lingcod	1.3	2.1
Greycod	2.8	2.7
Pollock	414.9	348.5
Blackcod	*	
Flounder	0.6	
Skate	0.3	98.3
Dogfish	116.7	
Eulachon	16.6	
Turbot	*	
Octopus	*	62.9
Roe (Salmon)	2.5	
Smelt	1.7	
Other Fish	6.3	

* Less than 500 kg

Table 3. Summary of fish capture data for the 11 sampling sites on Sturgeon Bank, May 26 to July 2, 1980.

Species	Total Catch	Composition (%)	Frequency of occurrence within catch (%)
Pacific herring: Clupea harengus pallasi	2906	38.90	14.5
Shiner perch: Cymatogaster aggregata	1753	23 47	10.1
Pacific sand lance: Ammodytes hexapterus	1298	17.38	4.0
Surf smelt: Hypomesus pretiosus pretiosus	591	7.91	5.4
Threespine stickleback: Gasterosteus aculeatus	443	5.93	13.8
Chinook salmon: Oncorhynchus tshawytscha	230	3.08	20.5
Pacific Staghorn sculpin: Leptocottus armatus	86	1.15	6.7
Chum salmon: Oncorhynchus keta	61	0.82	6.7
Starry flounder: Platichthys stellatus	49	0.66	8.4
Arrow goby: Clevelandia ios	18	0.24	2.4
Sockeye salmon: Oncorhynchus nerka	17	0.23	2.7
Pink salmon: Oncorhynchus gorbuscha	4	0.05	1.3
Coho salmon: Oncorhynchus kisutch	3	0.04	0.7
Crescent gunnel: Pholis laeta	3	0.04	0.3
Grunt sculpin: Rhamphocottus richardsoni	2	0.03	0.3
Peamouth chub: Mylochelis caurinus	2	0.03	0.7
Pacific snake prickleback: Lumpenus sagitta	1	0.01	0.3
Peapoint gunnel: Apodichthys flavidus	1	0.01	0.3
Masked greenling: Hexagrammos octogrammus	1	0.01	0.3
Hybrid sole: Inopsetta ischyra	1	0.01	0.3
Total	7470	100.00	

Table 4. Number and species of fish captured at each sampling site on Sturgeon Bank, May 26 to July 2, 1980

Species		South of Iona Jetty							North of Iona Jetty				Total
SITE:		1	3	4	5	6	7	8	2	9	10	11	
Distance from outfall (km):		(0.3)	(0.6)	(1.0)	(2.0)	(2.7)	(3.6)	(4.4)					
Pacific herring: Clupea harengus pallasi			10	186	12	24	70	82	113	1367	339	703	2906
Shiner perch: Cymatogaster aggregata				2	2	3	3	2	20	25	36	1660	1753
Pacific sand lance: Ammodytes hexapterus						2	3	105	2	557	626	3	1298
Surf smelt: Hypomesus pretiosus pretiosus				1		1	2	9		34	39	505	591
Threespine stickleback: Gasterosteus aculeatus				41	6	6	3	14	314	1	24	34	443
Chinook salmon: Oncorhynchus tshawytscha				16	8	12	18	35	20	34	43	44	230
Pacific Staghorn sculpin: Leptocottus armatus				3			4		67		10	2	86
Chum salmon: Oncorhynchus keta					3	13		2	4	8	8	23	61
Starry flounder: Platichthys stellatus			2	4	3	10	8		11		10	1	49
Arrow goby: Clevelandia ios						1			17				18
Sockeye salmon: Oncorhynchus nerka					1	1	2	11		1		1	17
Pink salmon: Oncorhynchus gorbuscha								1	2			1	4
Coho salmon: Oncorhynchus kisutch								2				1	3
Crescent gunnel: Pholis laeta											3		3
Grunt sculpin: Rhamphocottus richardsoni											2		2
Peamouth chub: Mylocheilis caurinus		2											2
Pacific snake prickleback: Lumpenus sagitta		1											1
Peapoint gunnel: Apodichthys flavidus											1		1
Masked greenling: Hexagrammos octogrammus												1	1
Hybrid sole: Inopsetta ischyra							1						1
Total	Number	3	12	253	35	73	114	263	570	2027	1141	2979	7470
	Species	2	2	7	7	10	10	10	10	8	12	13	18

Table 5. Results of Analysis of Variance and Newman-Keul's Test (α=0.05) applied to fish catch data (log X + 1) for each sampling site[1].

	All sites on the southern side of Iona Jetty	Sites 1 3 4 5 6 7 8 (south) vs 2 9 10 11 (north)	Sites 3 6 7 8 (south) vs 2 9 10 11 (north)
All species combined	1 3 5 4 6 7 8	significant	significant
Non-salmonids, all species combined	not significant	"	"
Pacific herring	" "	"	"
Salmonids, all species combined	1 3 5 4 7 6 8	"	"
Chinook salmon	1 3 5 6 4 7 8	"	"

[1] The solid line beneath the sites denotes homogeneous data sub-sets.

Table 6. Summary of water analysis data recorded at 11 sites on Sturgeon Bank, May 26 to July 2, 1980, at the time of fish capture.

	South of Iona jetty							North of Iona jetty			
Site:	1	3	4	5	6	7	8	2	9	10	11
Distance from outfall (km):	(0.3)	(0.6)	(1.0)	(2.0)	(2.7)	(3.6)	(4.4)				
Temperature (°C)	16.71	16.97	16.05	15.84	15.34	15.27	14.97	18.21	15.67	15.89	16.33
± S.D.	±2.65	±1.91	±2.22	±2.04	±1.93	±1.69	±1.97	±4.07	±2.06	±2.11	±2.02
(n)	(6)	(6)	(6)	(5)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
Conductivity (m mhos cm^{-1})	7.90	9.64	9.17	10.64	10.33	10.60	10.45	15.58	22.22	20.62	19.65
± S.D.	±5.81	±4.69	±2.89	±3.88	±4.83	±5.05	±5.67	±0.49	±8.59	±7.91	±8.23
(n)	(6)	(6)	(6)	(5)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
Dissolved oxygen (mg L^{-1})	5.66	4.94	7.15	8.94	8.83	9.89	9.80	7.41	8.49	8.57	9.04
± S.D.	±1.82	±1.28	±2.18	±2.49	±1.62	±0.72	±1.34	±2.14	±1.27	±1.51	±0.96
(n)	(6)	(6)	(6)	(5)	(6)	(6)	(6)	(6)	(5)	(6)	(6)
pH	7.05	7.13	7.33	7.74	7.90	7.97	8.02	7.85	7.97	7.97	8.02
± S.D.	±0.33	±0.18	±0.30	±0.29	±0.39	±0.26	±0.30	±0.37	±0.26	±0.20	±0.27
(n)	(6)	(6)	(6)	(5)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
Oxidation - reduction potential (meV)	+6	-9	-3	-18	+4	+2	-2	-22	-10	-13	-14
± S.D.	±136	±111	±106	±61	±70	±60	±59	±91	±48	±47	±45
(n)	(6)	(6)	(6)	(5)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
Dissolved oxygen (% air satn.)	60	55	75	95	95	105	105	85	95	95	100
± S D.	±20	±15	±20	±30	±15	± 5	±15	±30	±15	±15	±15
(n)	(6)	(6)	(6)	(5)	(6)	(6)	(6)	(6)	(6)	(6)	(6)

Table 7. Results of in-situ bioassay experiments with juvenile chinook salmon, and associated water chemistry data.

Site	Distance from outfall (km)	Number of experiments	Approximate range in time to 50% mortality (h)	Dissoloved oxygen mg L^{-1} ± S.D.(n) (range)	Temperature °C ± S.D. (n) (range)	pH ± S.D. (n) (range)	Conductivity mmhos cm^{-1} ± S.D. (n) (range)
1	0.03	5	<2 to 24	5.4 ± 1.9 (6) (3.2 - 7.4)	17.3 ± 1.1 (6) (15.5 - 18.2)	7.0 ± 0.2 (2) (6.8 - 7.1)	5.5 ± 2.9 (6) (0.8 - 9.8)
2	0.6	4	3 - 4 to <24	5.4 ± 1.6 (6) (3.4 - 7.6)	17.6 ± 1.3 (6) (15.5 - 19.0)	7.0 ± 0.3 (2) (6.8 - 7.2)	7.5 ± 3.1 (6) (2.8 - 12.3)
3	1.0	5	0.1 - 0.2 to <26	2.5 ± 2.7 (10) (0.2 - 7.6)	18.1 ± 1.3 (10) (15.5 - 19.5)	6.7 ± 0.1 (6) (6.5 - 6.9)	9.5 ± 1.9 (10) (4.8 - 11.8)
4	2.0	4	<0.2 to 3 - 25	4.2 ± 3.6 (6) (0.1 - 8.1)	17.7 ± 1.9 (6) (15.0 - 19.5)	6.7 (2)	8.9 ± 2.0 (6) (5.7 - 11.5)
5	2.2	1	<0.03	0.7 (1)	18.0 (1)	6.8 (1)	16.0 (1)
6	2.3	5	0.1 - 0.2 to <19	3.8 ± 3.0 (7) (0.4 - 7.8)	18.4 ± 0.8 (7) (17.0 - 19.4)	7.1 ± 0.4 (6) (6.6 - 7.8)	8.7 ± 3.6 (7) (4.6 - 13.5)
7	2.7	4	<2 to 29 - 52	6.6 ± 3.0 (7) (0.3 - 9.8)	17.4 ± 1.7 (7) (15.0 - 20.0)	7.0 ± 0.2 (3) (6.7 - 7.2)	7.0 ± 2.9 (7) (4.0 - 12.0)
8	3.6	2	52 - 70 to <96	7.1 ± 2.2 (7) (3.0 - 10.0)	17.2 ± 1.5 (7) (15.0 - 18.5)	7.0 ± 0.2 (3) (6.8 - 7.1)	7.3 ± 2.4 (7) (5.9 - 12.0)
9	4.4	2	52 - 70 to <96	8.0 ± 1.5 (7) (6.7 - 10.4)	17.0 ± 1.1 (7) (15.5 - 18.5)	7.2 ± 0.1 (3) (7.1 - 7.3)	6.7 ± 3.7 (7) (3.1 - 13.5)

Table 8. Dissolved oxygen concentrations (mg L^{-1} ± S.D.(n)) recorded at 0.5 m depth at different tidal heights over Sturgeon Bank during July and August 1981.

Tide Height (m)	State	Site: 4 1000 + 130 south	4 1000 + 230 south	4 1000 + 560 south	4 2000 + 130 south	5 2000 + 260 south	5 2000 + 560 south	*con. 2200 + 130 south	*con. 2200 + 260 south	6 2700 + 130 south	6 2700 + 260 south	6 2700 + 560 south	7 3600 + 130 south	7 3600 + 260 south	7 3600 + 560 south
		Site and distance (m) from outfall and from Iona jetty													
4.0 - 3.1	ebb	4.1±3.7 (2)	4.3±4.1 (2)	7.6±0.04 (2)	8.4±0.5 (2)	8.6±0.1 (2)	8.82 (1)	8.7±0.2 (2)	8.5±0.4 (2)	8.7±0.2 (2)	8.5 (1)	8.1 (1)	8.7±0.03 (2)	8.8±0.1 (2)	8.9±0.2 (2)
3.0 - 2.1	ebb	2.0±2.9 (4)	** -	-	0.8±0.2 (3)	0.7±0.1 (2)	4.8±2.9 (4)	6.4±1.0 (3)	6.3±1.2 (3)	6.0±4.9 (3)	8.6±0.3 (2)	8.7±0.03 (2)	6.6±4.2 (4)	6.0±2.1 (4)	4.1 (1)
2.0 - 1.1	ebb	2.4±1.5 (5)	-	-	1.0±1.1 (6)	-	3.8±1.6 (3)	2.8±2.2 (7)	3.4±1.7 (5)	3.1±3.1 (7)	5.0±0.8 (6)	-	3.8±2.4 (6)	4.2±0.4 (2)	5.0±4.2 (2)
1.1 - 2.0	flood	4.4±0.6 (4)	-	-	2.0±1.7 (8)	-	2.4±0.2 (2)	2.8±2.5 (5)	4.4±1.4 (4)	2.4±2.5 (6)	4.8±2.7 (5)	-	4.8±2.5 (5)	5.1 (1)	
2.1 - 3.0	flood		-	-	3.5±0.3 (2)	-	-	4.7±3.2 (3)	5.4±3.3 (3)	5.6 (1)	-	4.1 (1)	8.2 (1)	8.8 (1)	9.3 (1)

*con - confluence of natural drainage and effluent channels
** - water too shallow to be accessed by boat or bank dry

Table 9. Dissolved oxygen concentrations (mg L^{-1}) 3.6 km from the Iona Island sewage outfall, along the effluent channel (number of determinations in parentheses).

Tide height (m)	State	Depth (m)	Dissolved oxygen (mean ± S.D.) (n) 0.0	0.5	1.0	1.5	2.0	2.5
4.0 - 3.1	ebb		8.7 (2)	8.7 (2)	8.5 (2)	8.4 (2)	n.d	n.d
3.0 - 2.1	ebb		6.6±4.2 (4)	5.0±4.4 (4)	4.4±4.4 (4)	5.2±4.4 (3)	3.8±3.3 (3)	3.6±3.6 (3)
2.0 - 1.1	ebb		3.8±2.4 (6)	3.0±1.9 (6)	3.3±1.7 (6)	3.5±1.6 (6)	3.1±1.5 (6)	2.7±1.7 (6)
1.0 - 0	ebb		0.6±0.5 (5)	1.1±1.0 (4)	2.2±1.6 (5)	2.3±1.2 (5)	2.5±1.3 (4)	3.1±1.1 (2)
0 - 1.0	flood		0.3±0.1 (4)	0.6±0.7 (4)	0.7±0.5 (4)	1.2±0.8 (4)	1.6±1.6 (4)	nd
1.1 - 2.0	flood		4.8±2.5 (5)	5.6±3.0 (7)	5.5±2.6 (7)	5.5±1.9 (7)	5.0±2.7 (7)	5.2±2.6 (6)
2.1 - 3.0	flood		8.2 (1)	7.9 (1)	8.7 (1)	*nd	nd	nd
3.1 - 4.0	flood		8.9 (1)	8.8 (1)	8.7 (1)	8.5 (1)	8.4 (1)	7.6 (1)

*nd = no determination

Table 10. Organic compounds identified by Radian Corporation (1979) in Iona Island sewage effluent (not chlorinated) and on starry flounder from Sturgeon Bank (site SB-1).

Compounds	Flounder	Sewage
Phenol	x	x
2-Nitrophenol		x
2,4-Dimethylphenol		x
2,4,6-Trichlorophenol	x	x
2-Chlorophenol	x	x
2,4-Dichlorophenol		x
4-Chloro-3-Cresol	x	x
Pentachlorophenol	x	x
α-Endosulfan	x	x
4,4'-DDE	x	x
Dieldrin	x	x
4,4'-DDD	x	x
β -Endosulfan	x	x
4,4'-DDT	x	x
Heptachlor epoxide	x	x
α-BHC	x	x
Naphthalene	x	[a]x
Heptachlor	x	
Aldrin	x	
α-BHC	x	
PCB	x	
	(n = 10, 1978)	(n = 3, 1979)

[a]some naphthalene was present in the internal standard used in the analysis. However, the impurity probably accounted for only a portion of the total amount indicated in the analysis.

Table 11. Levels of PCB's determined by Radian Corporation (1980) in flounder and juvenile chinook samples collected on Sturgeon and Roberts Bank in August and November 1978.

Sampling Time	Site	Species	PCB (ppb wet weight)
August	SB-1	flounder	640
	SB-2	flounder	660
	RB-1	flounder	2*
	SB-2	salmon	44
November	SB-1	flounder	167
	SB-2	flounder	ND
	RB-1	flounder	1*

ND = not detected
* values below the limit of confident identification

Table 12. Volatile organic compounds present in receiving water samples from Sturgeon Bank, August 1981.

Chloroform
Methylene chloride
Trichloroethylene
Tetrachloroethylene
Benzene
Toluene
Xylene (two isomers)
Methyl isobutyl ketone
Ether
Ethylene glycol monomethyl ether
n-Butanol

Table 13. Organic contaminants in fish and receiving water samples from Sturgeon Bank, August 1981.

Compounds Identified	Starry Flounder	Staghorn Sculpin	Shiner Perch	Water
Benzaldehyde	x	x		
Phenylacetaldehyde	x	x		
Phenylacetic Acid	x	x	x	x
Hydroxy Benzoic Acid	x			
Hydroxyphenylacetic Acid	x	x		
Glutaric Acid	x	x		
Dichloroanisole	x	x		
Diethyl Phthalate	x	x		
Naphthalene	x			
Two Unknown Phenols	x	x		
Benzoic Acid		x		x
α-Terpineol		x		
1,2-Dichloroethyltoluene		x		
Caffeine				x
Phenylpropionic Acid				x
	n = 13	n = 1	n = 1	n = 2

Figure 1. Location of the Iona Island sewage treatment plant.

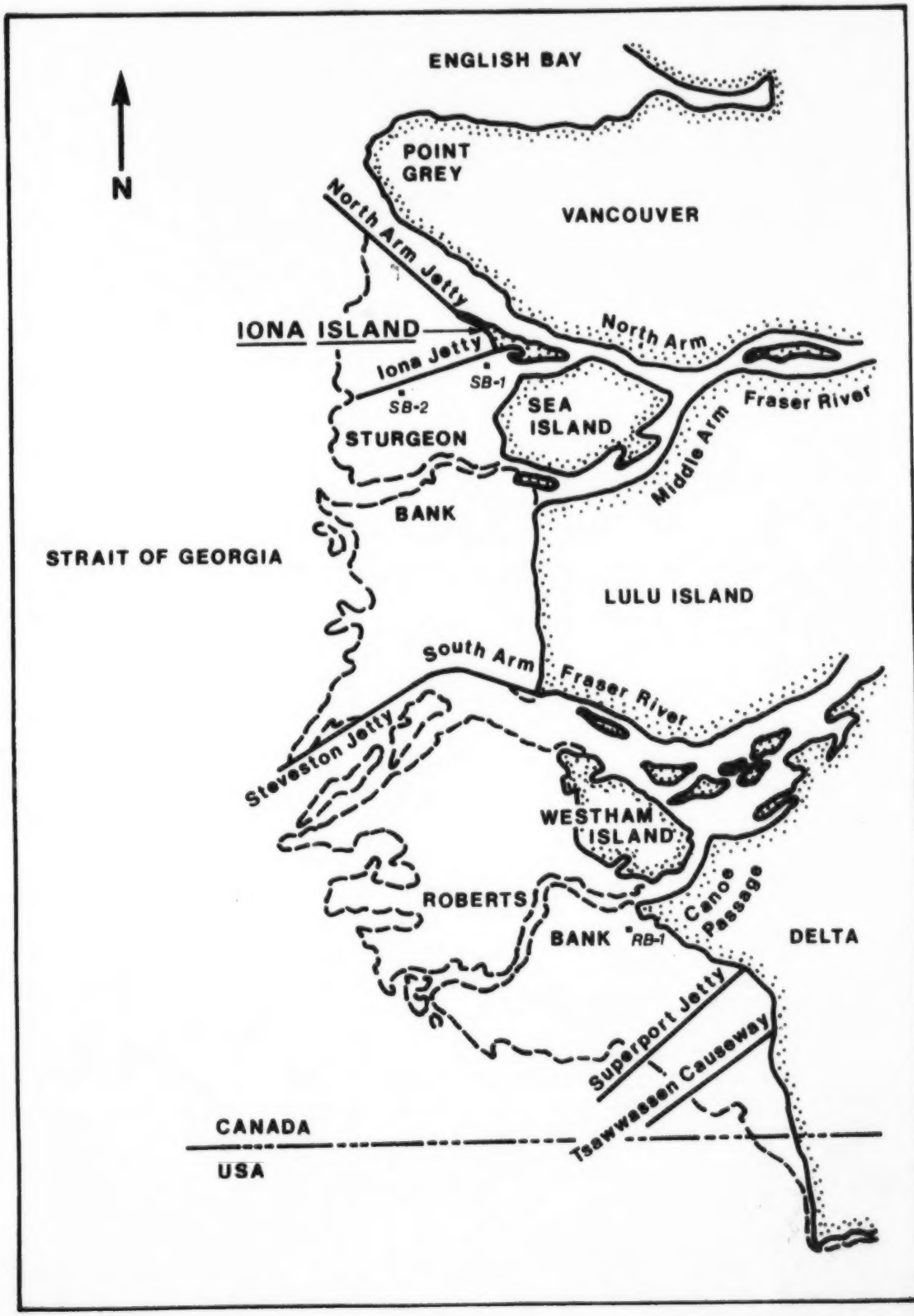

ENGLISH BAY
N
POINT GREY
VANCOUVER
North Arm Jetty
IONA ISLAND
Iona Jetty
North Arm
SB-1
SB-2
SEA ISLAND
Fraser River
STURGEON BANK
Middle Arm
STRAIT OF GEORGIA
LULU ISLAND
South Arm
Fraser River
Steveston Jetty
WESTHAM ISLAND
ROBERTS BANK
RB-1
Canoe Passage
DELTA
Superport Jetty
Tsawwassen Causeway
CANADA
USA

Figure 2. Site locations used for bioassay experiments and fish capture.

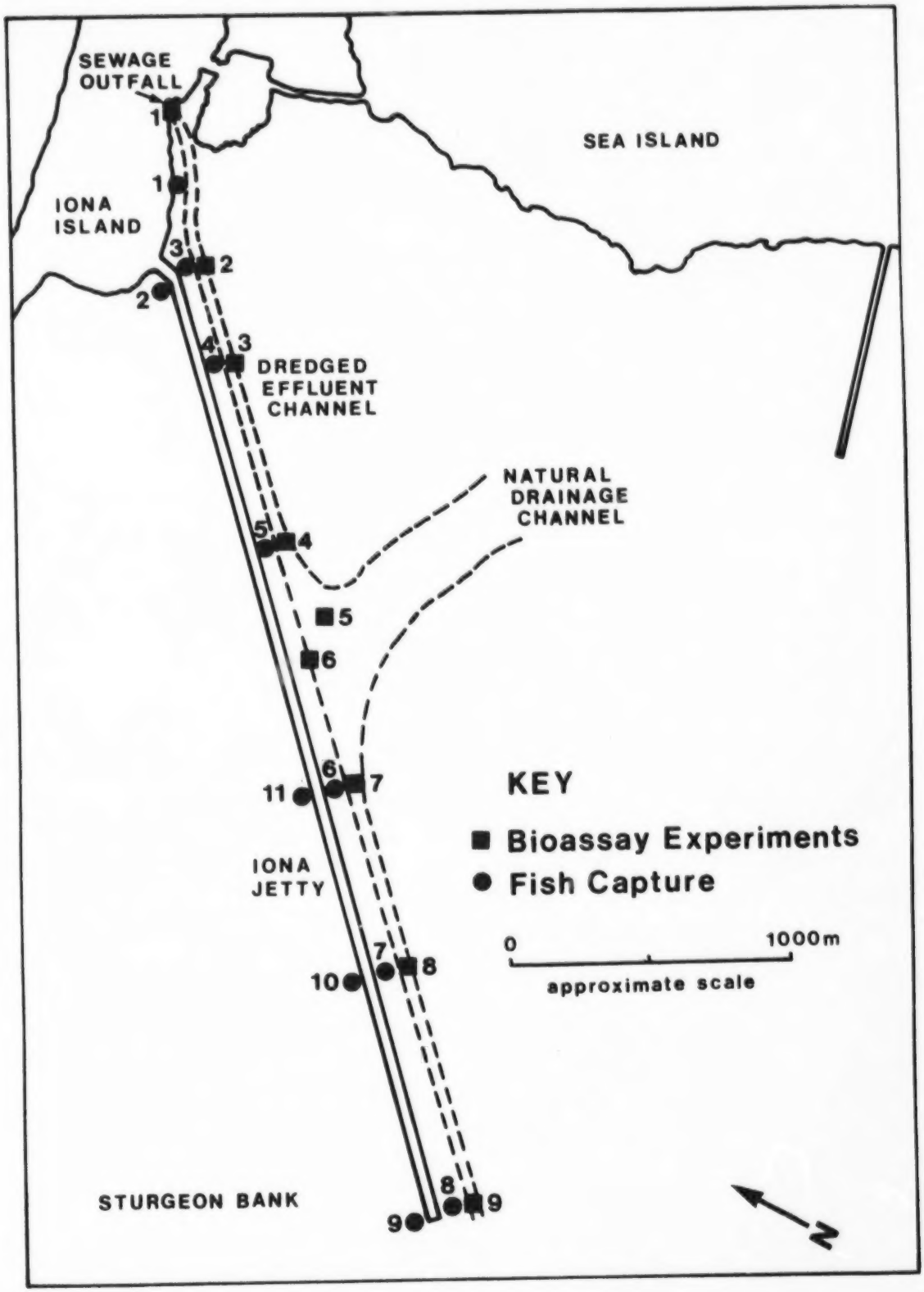

SEWAGE OUTFALL
SEA ISLAND
IONA ISLAND
DREDGED EFFLUENT CHANNEL
NATURAL DRAINAGE CHANNEL
IONA JETTY
STURGEON BANK
KEY
Bioassay Experiments
Fish Capture
0
1000m
approximate scale
N

Figure 3. Relative abundance and distribution of fish at high tide.

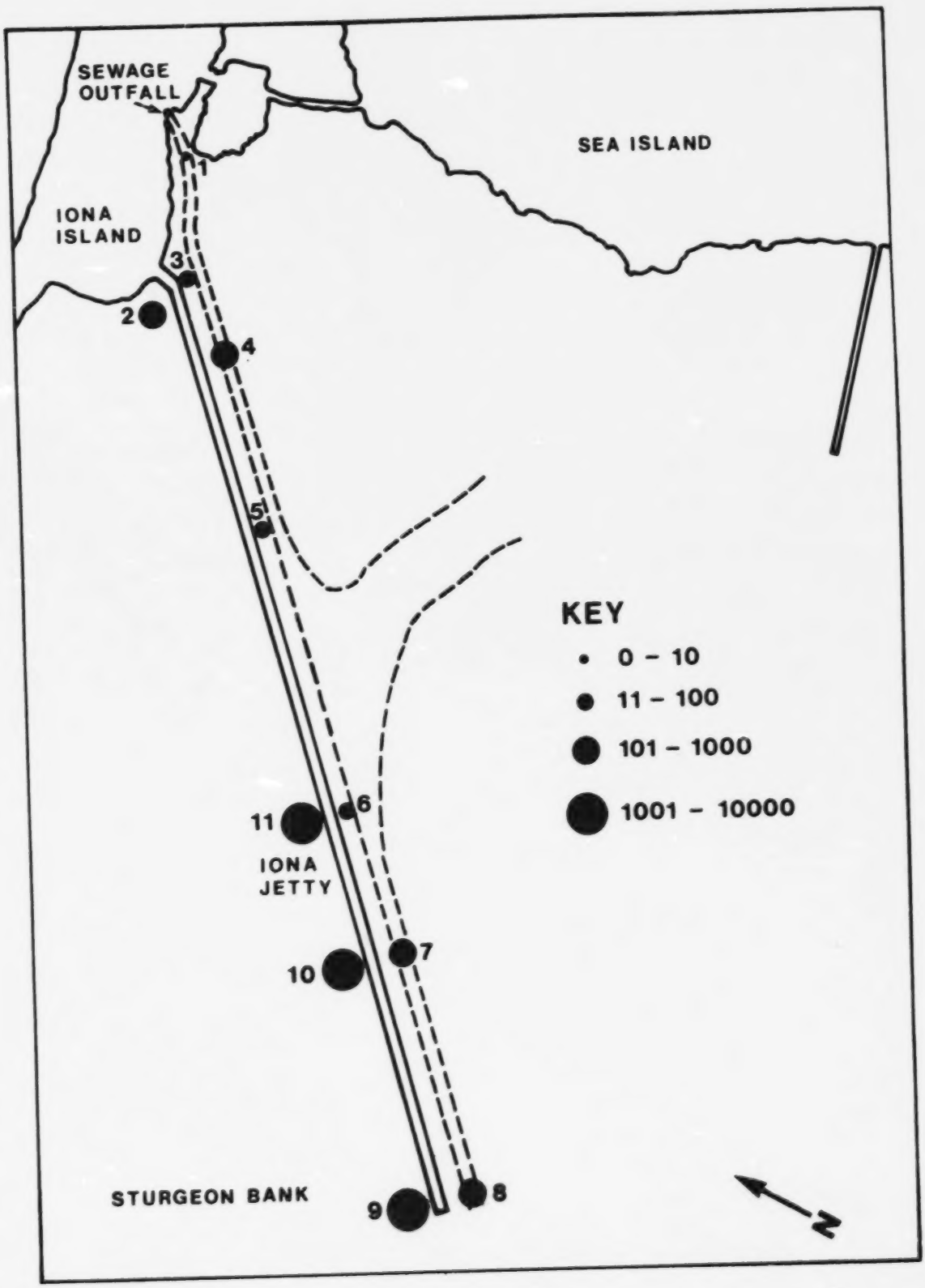

SEWAGE OUTFALL
SEA ISLAND
IONA ISLAND
1
2
3
4
5
6
7
8
9
10
11
IONA JETTY
STURGEON BANK
KEY
0 – 10
11 – 100
101 – 1000
1001 – 10000
N

Figure 4. Minimum time to 50% mortality (h) of chinook salmon in bioassay experiments.

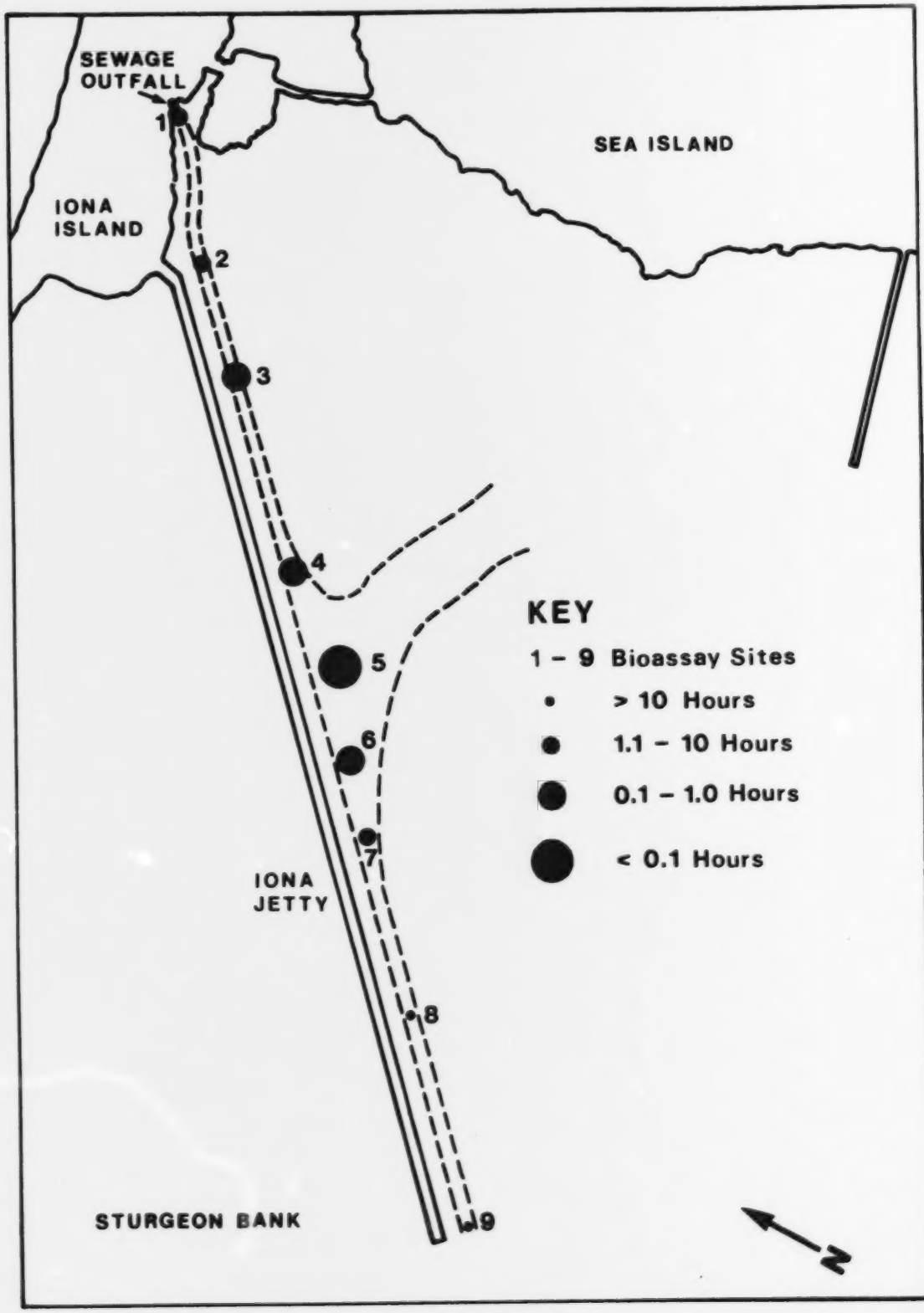

SEWAGE OUTFALL
1
SEA ISLAND
IONA ISLAND
2
3
4
5
6
7
IONA JETTY
8
9
STURGEON BANK
KEY
1 - 9 Bioassay Sites
> 10 Hours
1.1 - 10 Hours
0.1 - 1.0 Hours
< 0.1 Hours
N

Figure 5. Surface water dissolved oxygen concentrations, mg L^{-1}, July 8, 1980 - ebb tide.

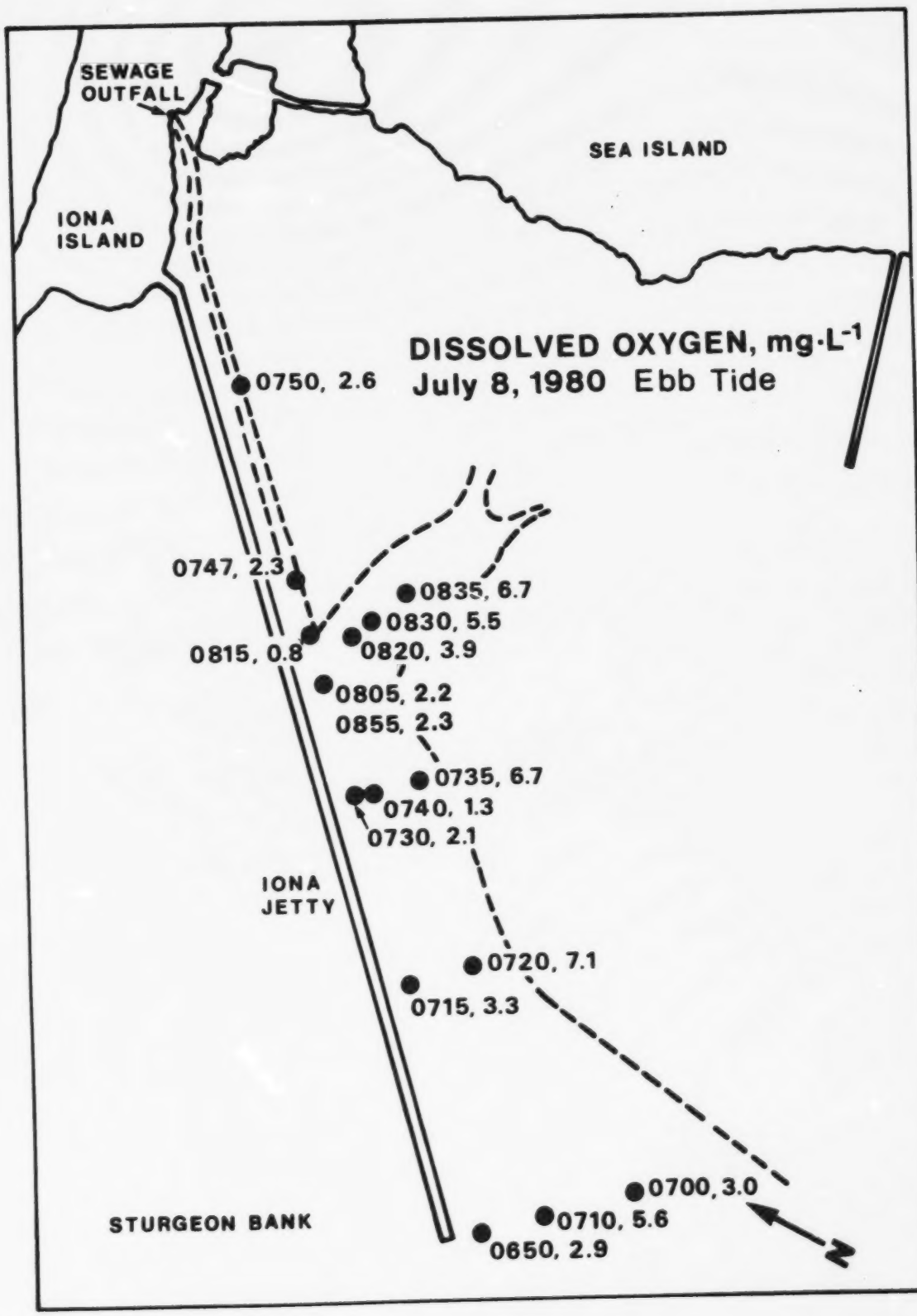

SEWAGE OUTFALL
SEA ISLAND
IONA ISLAND
DISSOLVED OXYGEN, mg·L-1
July 8, 1980 Ebb Tide
0750, 2.6
0747, 2.3
0835, 6.7
0830, 5.5
0815, 0.8
0820, 3.9
0805, 2.2
0855, 2.3
0735, 6.7
0740, 1.3
0730, 2.1
IONA JETTY
0720, 7.1
0715, 3.3
0700, 3.0
0710, 5.6
0650, 2.9
STURGEON BANK
N

Figure 6. Surface water dissolved oxygen concentrations, mg L^{-1}, July 8, 1980 - flood tide.

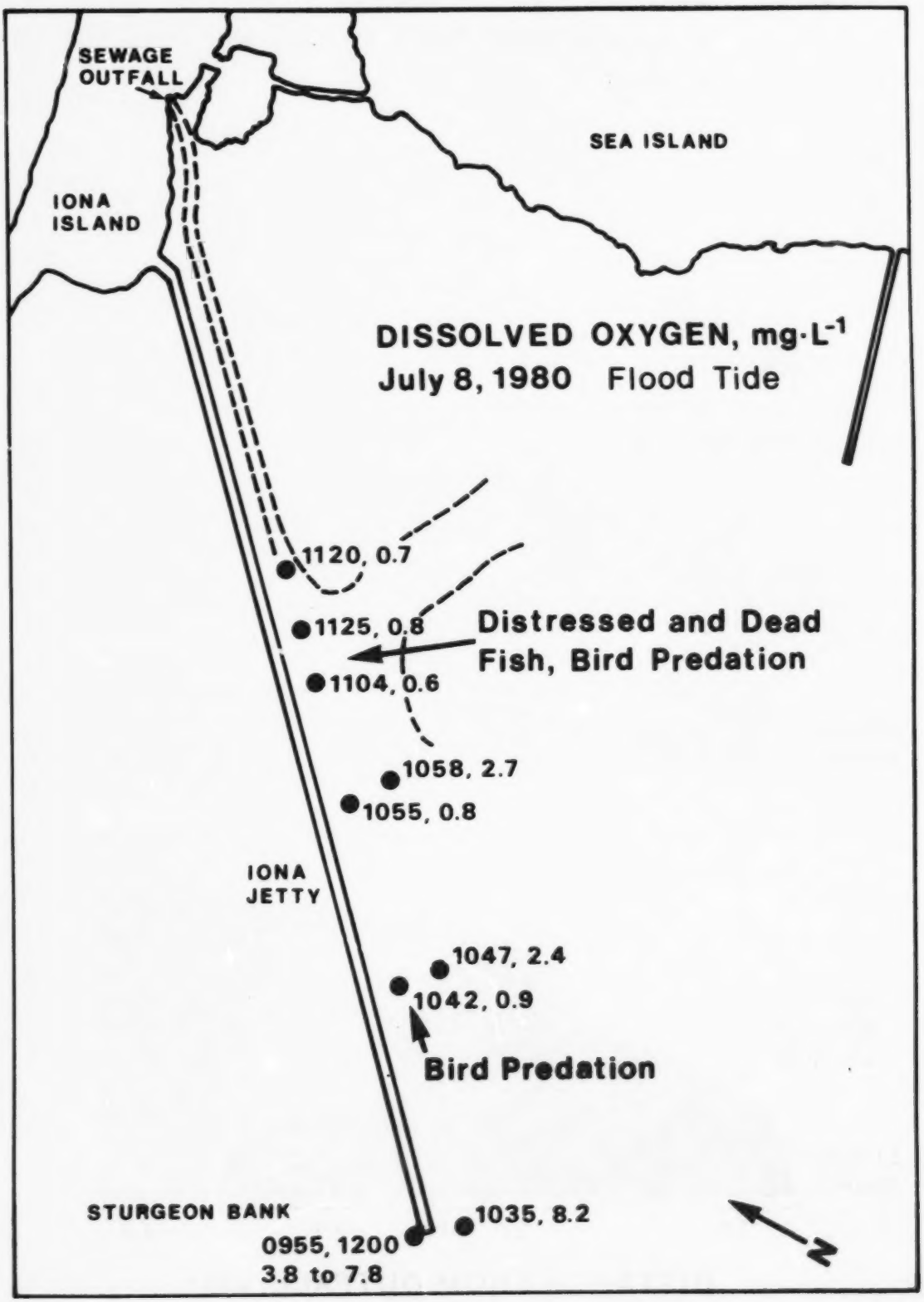
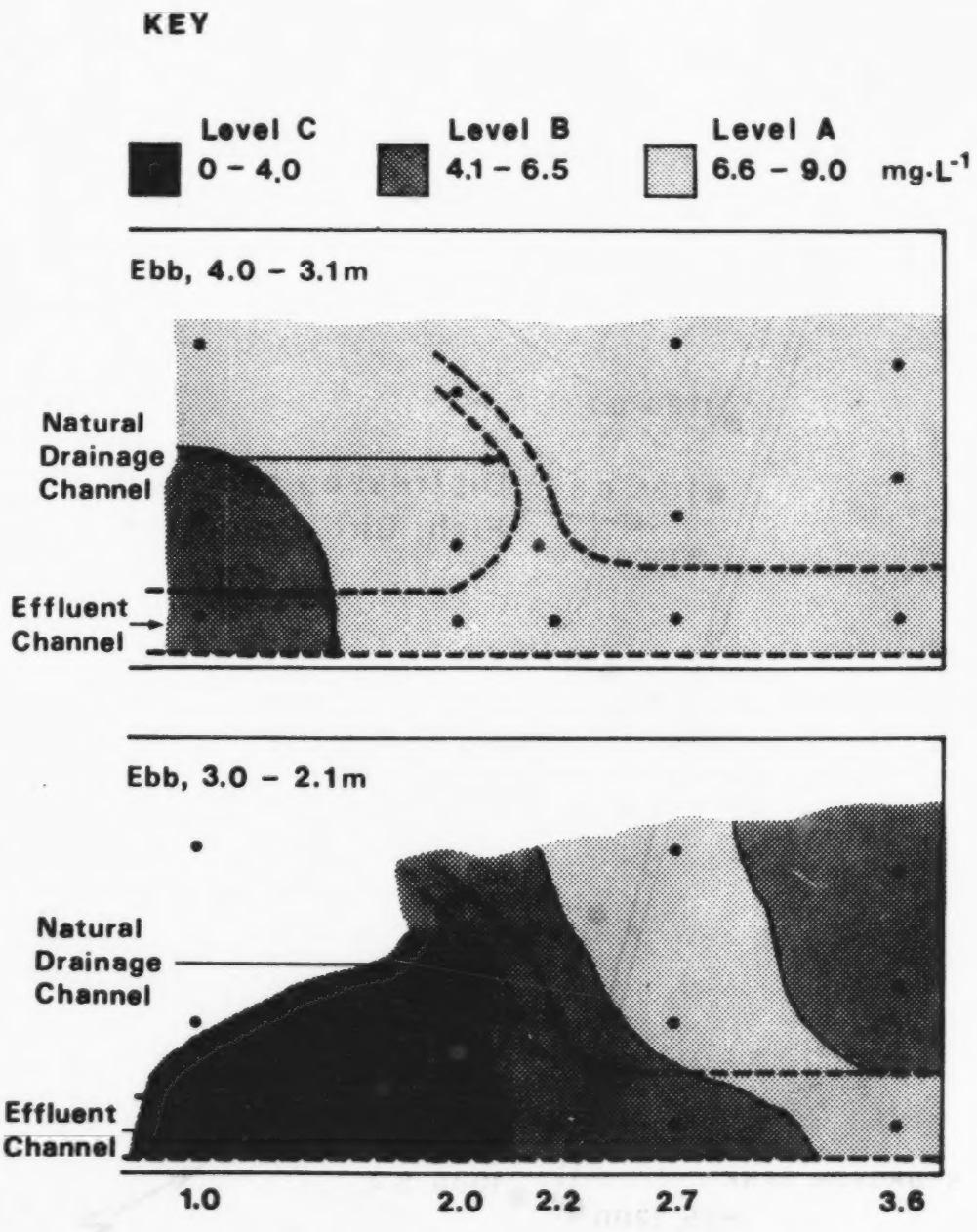

SEWAGE OUTFALL
SEA ISLAND
IONA ISLAND
DISSOLVED OXYGEN, mg·L-1
July 8, 1980 Flood Tide
1120, 0.7
1125, 0.8
Distressed and Dead Fish, Bird Predation
1104, 0.6
1058, 2.7
1055, 0.8
IONA JETTY
1047, 2.4
1042, 0.9
Bird Predation
STURGEON BANK
1035, 8.2
0955, 1200
3.8 to 7.8
N

FIGURE 7 Surface water dissolved oxygen concentrations over Sturgeon Bank 1 to 3.6 km from the sewage outfall.



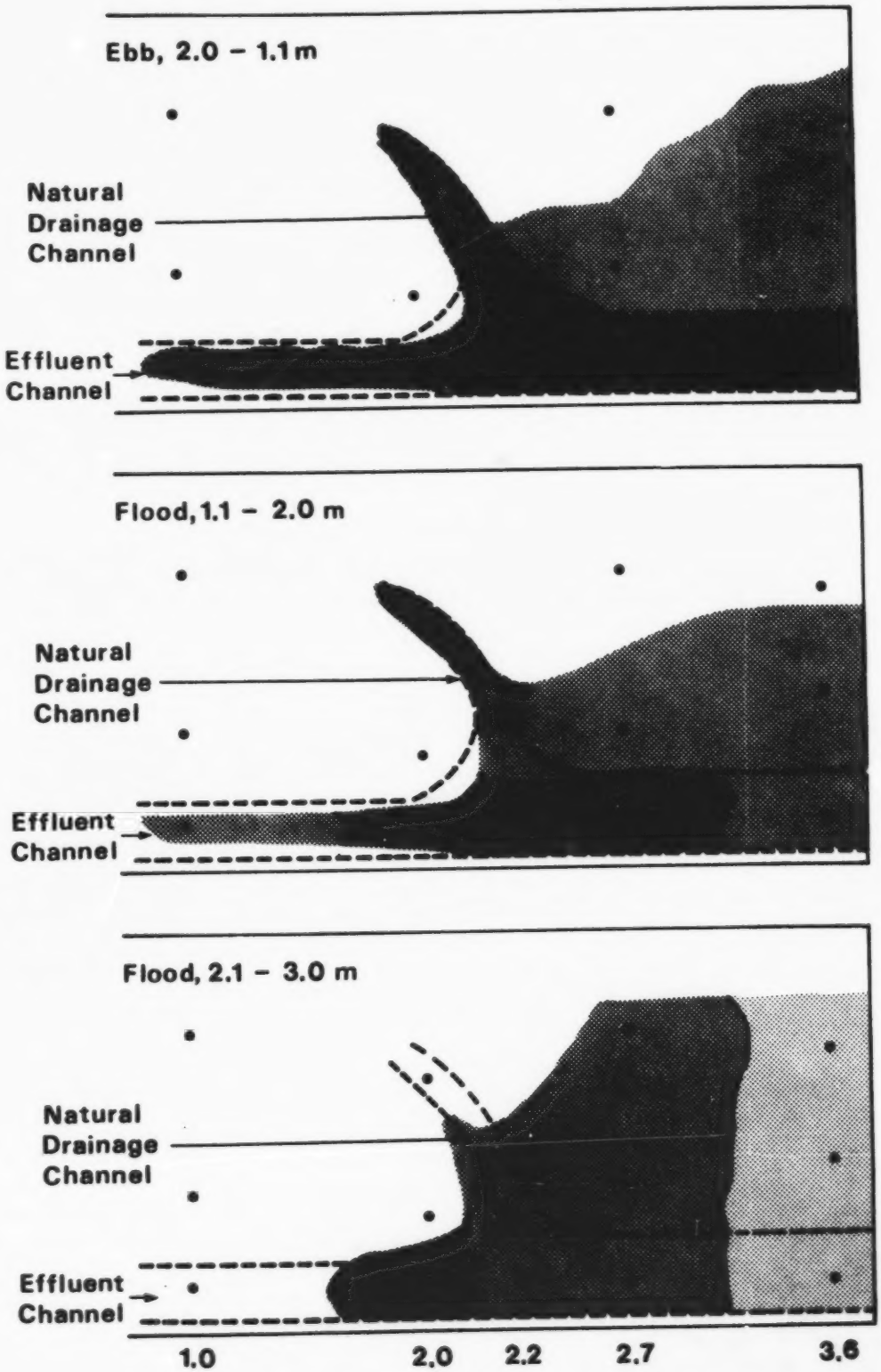

Ebb, 2.0 – 1.1 m
Natural
Drainage
Channel
Effluent
Channel
Flood, 1.1 – 2.0 m
Natural
Drainage
Channel
Effluent
Channel
Flood, 2.1 – 3.0 m
Natural
Drainage
Channel
Effluent
Channel
1.0
2.0
2.2
2.7
3.6
DISTANCE FROM OUTFALL, km

Figure 8. Dissolved oxygen profiles within the sewage effluent channel, July 14 - August 14, 1981, at different tidal heights.

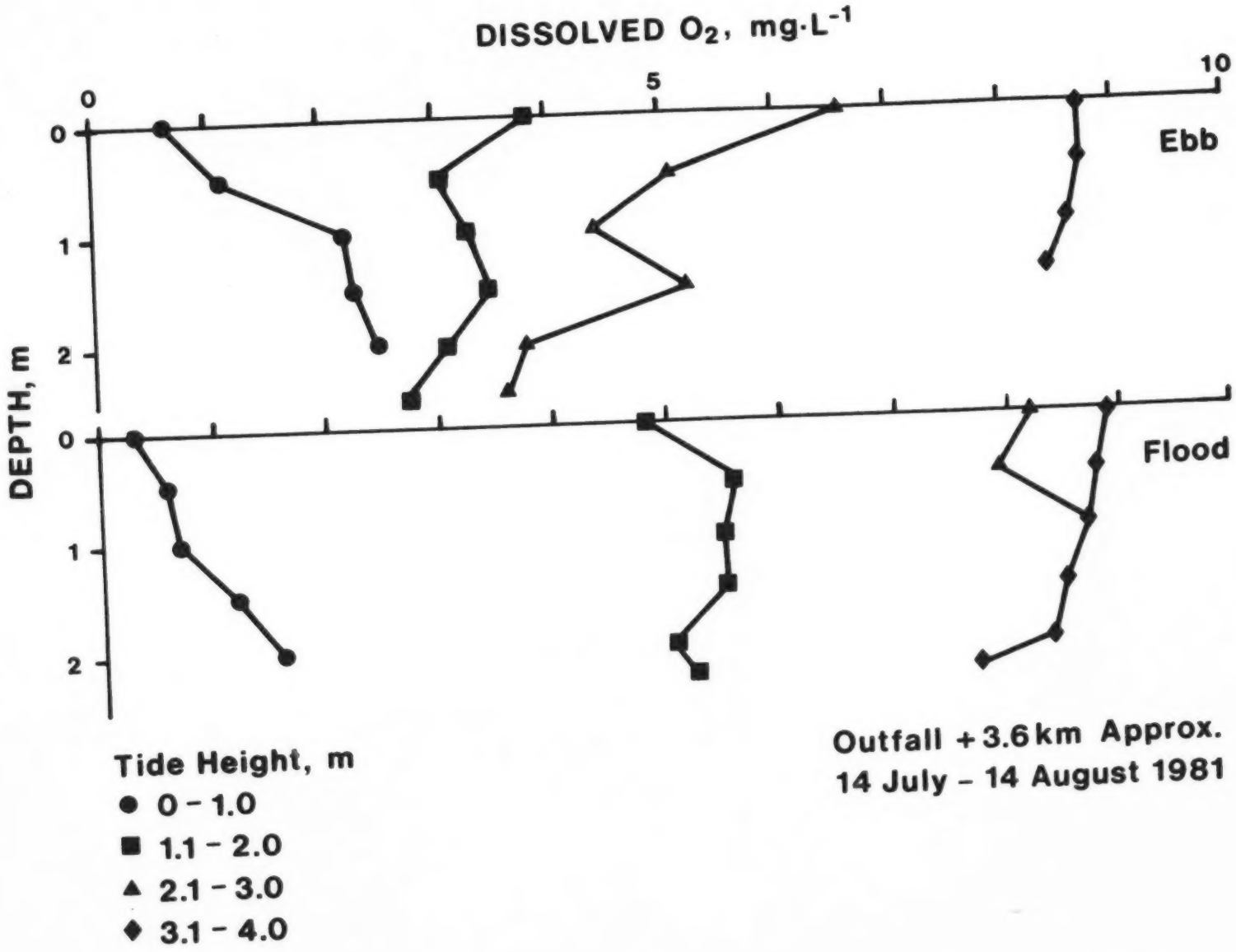
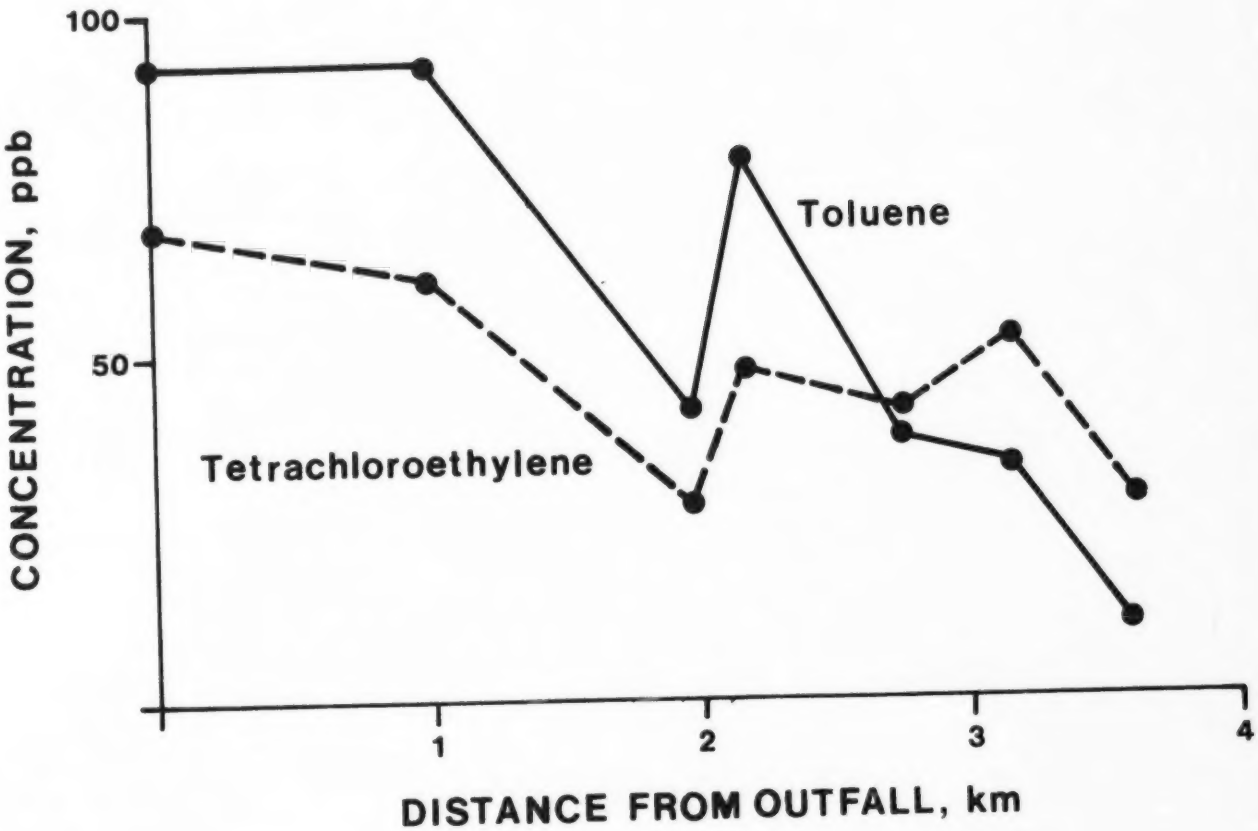

DISSOLVED O_2, $mg \cdot L^{-1}$
0
5
10
Ebb
Flood
DEPTH, m
0
1
2
Tide Height, m
● 0 - 1.0
■ 1.1 - 2.0
▲ 2.1 - 3.0
◆ 3.1 - 4.0
Outfall + 3.6 km Approx.
14 July - 14 August 1981

Figure 9. Concentrations (ppb) of toluene and tetrachloroethylene in surface waters of Sturgeon Bank, August 1982.


100
50
CONCENTRATION, ppb
Toluene
Tetrachloroethylene
1
2
3
4
DISTANCE FROM OUTFALL, km